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Ministry of Environment

ENVIRONMENTAL PROTECTION DIVISION
ENVIRONMENTAL SUSTAINABILITY DIVISION
MINISTRY OF ENVIRONMENT

Water Quality Assessment and Objectives for Windermere Lake

TECHNICAL REPORT

FIRST UPDATE

November 2010

Prepared by:

Alison Neufeld
Environmental Protection Division

Les Swain
Tri-Star Environmental Consulting

Kevin Rieberger
Environmental Sustainability Division

Approved By: ______________________________ ______________
Lynn Kriwoken, Director
Water Protection & Sustainability
Environmental Sustainability Division

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EXECUTIVE SUMMARY

Windermere Lake is a very popular vacation destination and has experienced considerable development over the last decade. The Windermere Lake watershed is a multi-use watershed, with high demands for recreation, aquatic life, livestock watering and grazing, forest harvesting and source water for the public water supply. The predominant human uses of water in this watershed are for recreation and the public water supply (drinking water and irrigation).

The Ministry of Environment (MoE) developed water quality objectives for Windermere Lake in 1985 (Table 1; McKean and Nordin 1985). Water quality monitoring was conducted between 2006 and 2009 to provide current data to re-assess existing objectives in order to ensure that development near the lake is not impacting water quality, and to review the 1985 objectives and revise these as necessary.

The results of this monitoring showed there has not been any substantial change in the water quality of Windermere Lake compared to historical data. Windermere Lake is shallow and well mixed, with an average water residence time of approximately 47 days. These factors, combined with the amount of inflow received from the Columbia River, allow Windermere Lake to effectively assimilate nutrients.

Elevated concentrations of microbiological indicators were noted at both Athalmer and Invermere beaches. This is likely due to the beaches being located in embayments, as well as the high recreational use of these areas. In addition, the use of septic systems along the east shore of the lake may also be contributing inputs. Water quality results from the three main lake stations did not display much variation over the three year monitoring period. It is possible that impacts from non-point sources of pollution may be more evident in near-shore areas.

The water quality objectives for Windermere Lake have generally been met. Temperature exceeded the water quality guidelines for the protection of aquatic life; however these elevated temperatures appear to be natural. Average temperatures to protect aquatic life

have been recommended for Windermere Lake. Objectives for the following variables have been added or modified since the 1985 assessment: phosphorus, microbiological indicators, turbidity, total organic carbon, temperature and dissolved oxygen. The new and modified objectives will help prevent inputs from non-point sources of contaminantion from impairing water quality.

Summary of existing and proposed water quality objectives for Windermere Lake (see Tables 3 and 15 for complete details).

Variable	Original Objectives (1985)		Revised Objectives (2010)	
	Site	**Objective**	**Site**	**Objective**
Turbidity	0200051 0200052 E262793	≤ 1 NTU (average)	0200051 0200052 E262793	≤ 1 NTU (average) clear-flow period
		5 NTU (maximum)		≤ 5 NTU (maximum) clear-flow period
				5 NTU (95^{th} percentile) turbid-flow period
Phosphorus	0200051 0200052 E262793	≤ 0.010 mg/L (average)	0200051 0200052 E262793	10 µg/L (maximum)
Fecal coliforms	Bathing Beaches	≤ 200 MPN/100 mL (geo. mean) ≤ 400 MPN/100 mL (90^{th} percentile)		
	Near Drinking Water Intakes	≤ 10 MPN/100 mL (90^{th} percentile)		
Temperature			0200051 0200052 E262793	20 °C June (average)
				25 °C July (average)
				23 °C August (average)
E. coli			Bathing Beaches	≤ 77 CFU/100 mL (geo. mean)
			Drinking Water Intakes	≤ 10 CFU/100 mL (90^{th} percentile)
TOC			Near Drinking Water Intakes	4 mg/L (maximum)
DO			0200051 0200052 E262793	≥ 5 mg/L (instantaneous minimum)
				≥ 8 mg/L (average)

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Acknowledgements

This first update report is based on the original water quality assessment and objectives for Windermere Lake prepared by Rick Nordin and Colin McKean from the Ministry of Environment in 1985. The following people are gratefully acknowledged for their work in preparing the First Update: Les Swain of Tri-Star Environmental for writing the first draft of the report; and, Heather Leschied and Kalista Pruden of Wildsight and the Lake Windermere Project for field data collection and data quality assurance. In addition, Heather Leschied also provided valuable information and insight throughout the reporting process.

The Lake Windermere Project was made possible by generous financial support from the Real Estate Foundation of British Columbia, Columbia Basin Trust, Environment Canada Eco Action, District of Invermere, Regional District of East Kootenay, Columbia Valley Local Conservation Fund, the Lake Windermere Ambassadors, Columbia Valley Community Foundation, Royal Bank of Canada, Unilever Canada, Habitat Conservation Trust Foundation, and TD Friends of the Environment, with inkind support from the BC Lake Stewardship Society, Canadian Columbia River Inter-Tribal Fisheries Commission, Fisheries and Oceans Canada, District of Invermere; East Kootenay Conservation Program, East Kootenay Integrated Lake Management Partnership, Interior Health Authority, Living Lakes, Ministry of Environment, No Water No Life, UK Environment Agency, Lake District National Park Authority, Regional District of East Kootenay, University of Waterloo Water Policy and Governance Group, and Waterlution.

Special thanks are given to Wildsight for facilitating The Lake Windermere Project and to the volunteers who made the project possible.

1. INTRODUCTION

Windermere Lake is a very large widening in the Columbia River, just downstream from Columbia Lake, and is at the headwaters of the Columbia River. It was once known as Lower Columbia Lake. The village of Windermere is located on the east side of the lake, and the larger town of Invermere is located on the lake's northwestern corner. The average depth of the lake is 3.4 m and the surface area is 1,610 ha. The lake is oriented in the north-south direction and flows to the north (Figure 1).

Windermere Lake is a very popular vacation destination. The western side of the lake, which fronts the Purcell Mountains, has a railroad running along its shore, and as a result, housing and recreational development is minimal. The eastern side of the lake has a more extensive flatland between the lake and the Rocky Mountains and has experienced considerable development including cottages, campgrounds, recreational beaches, golf courses and various tourist attractions.

The Windermere Lake watershed is a multi-use watershed with high demands for recreation, aquatic life, livestock watering and grazing, forest harvesting, mining and source water for the public water supply (drinking water and irrigation). As a multi-use watershed, there are a number of potential influences on water quality within the watershed.

The Ministry of Environment (MoE) developed water quality objectives for Windermere Lake in 1985 (Table 1; McKean and Nordin 1985), partly in response to a proposal to divert the Kootenay River into the Columbia River for the increased production of hydroelectric power. The proposed diversion was never undertaken. Water quality objectives provide policy direction for resource managers, serve as a guide for issuing permits, licenses, and orders by the MoE, and establish benchmarks for assessing water quality.

Water quality objectives are established in British Columbia for water bodies on a site-specific basis. An objective can be a physical, chemical or biological characteristic of water, biota or

sediment, which will protect the most sensitive designated water use at a specific location with an adequate degree of safety. Water quality objectives are based on water quality guidelines developed or adopted by the Ministry that relate the effects of water quality characteristics to designated water uses.

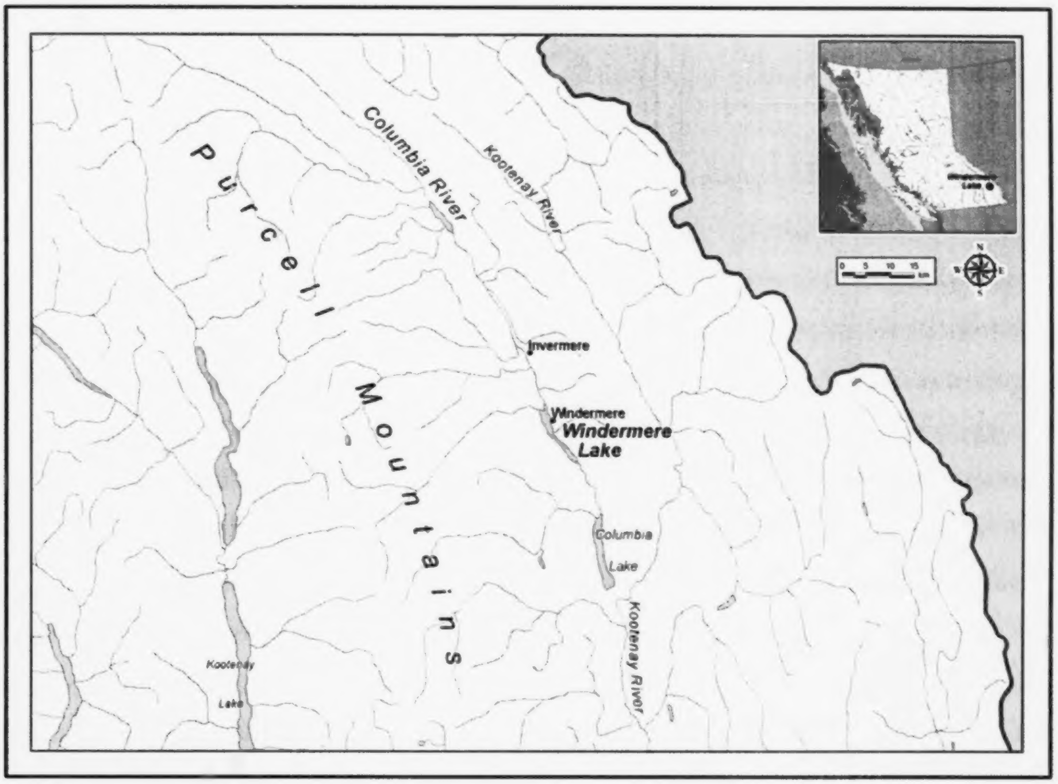


Figure 1. Location of Windermere Lake.

Table 1. Existing water quality objectives for Windermere Lake (McKean and Nordin 1985).

Designated water uses	Source waters used for drinking water, aquatic life, recreation, irrigation
Fecal coliforms (near water intakes)	$\leq$ 10 MPN/100 mL (90th percentile)
Fecal coliforms (at bathing beaches)	$\leq$ 200 MPN/100 mL (geometric mean) $\leq$ 400 MPN/100 mL (90th percentile)
Turbidity	$\leq$ 1 NTU (average) 5 NTU (maximum)
Total phosphorus	$\leq$ 0.010 mg/L (average)

2. WATERSHED DESCRIPTION

2.1 Basin Profile

Windermere Lake is located in the eastern portion of British Columbia in the Rocky Mountain Trench at an elevation of 800 m (Figure 1). Windermere Lake and Columbia Lake (located to the South but upstream) are the headwaters for the Columbia River. The lake is used extensively for recreation. The physical attributes of the lake are listed in Table 2 (Urban Systems 2001) while a bathymetric map of the lake is provided in Appendix 1. McKean and Nordin (1985) estimated the water retention time to be 0.13 years (47 days).

The long, narrow shape of Windermere Lake and long fetch can lead to high wave action due to winds. In addition, it is only about 3 m maximum depth at its southern end, which could result in scouring of the bottom and high turbidity levels due to the wave action.

The bedrock geology of the area is typically metamorphosed sedimentary rock, with some volcanic intrusions. The sedimentary rock is composed of dolomite, limestone, and shales (McKean and Nordin 1985).

Table 2. Physical characteristics of Windermere Lake.

Volume	55.19×10^6 m^3
Surface Area	1,610 ha
Littoral Area	~ 1,530 ha
Drainage	1,340 km^2
Maximum Depth	6.4 m
Mean Depth	3.4 m
Length	17.7 km
Average Width	1.1 km
Shoreline perimeter	36.3 km

Windermere Lake is located in the Southern Interior Mountains Ecoprovince. There are two distinct climate regimes; one in the mountains and the other in the Southern Rocky Mountain Trench. Air masses approach from the west and lose moisture, first as they pass over the western Columbia Mountains, and again as they pass over the Rocky Mountains. The Southern Rocky Mountain Trench bisects two large mountain blocks with significantly different physiographic and macroclimatic processes. During the summer, intense surface heating creates strong updrafts in the hills. The resulting downdraft over the centre of the valley clears the skies and enhances the sunny conditions. During the winter and early spring, the trench serves as an access route for outbreaks of cold, dense Arctic air (BC Ministry of Environment 2009a).

Vegetation is dominated by three zones: the Interior Cedar - Hemlock Zone in the lower to mid-slopes of the Columbia Mountains and wetter locations in the Rocky Mountains and trench; the Engelmann Spruce -Subalpine Fir Zone on the middle slopes of all mountains; and, the Alpine Tundra Zone on the summits of those mountains. The Ponderosa Pine Zone occurs in the Southern Rocky Mountain Trench, as does the Interior Douglas-fir Zone (BC Ministry of Environment 2009a).

3. HYDROLOGY AND CLIMATE

3.1 Hydrology

The main tributary watersheds to Windermere Lake are the Columbia River, Windermere, Madias and Holland creeks from the east, and Abel, Goldie, Brady and Johnston creeks from the west (Figure 2). Windermere Creek enters Windermere Lake at Windermere and drains 85 km^2. Madias Creek flows in a westerly direction and enters Windermere Lake at the southern tip of the lake. Abel Creek drains into Windermere Lake on the northwest shoreline, 2 km from the lake's outflow. Goldie Creek is situated 2 km south from Abel Creek on the west side of Windermere Lake. Johnston Creek is situated on the southwest side of the lake and Holland Creek drains into Windermere Lake on the northeast side.

Hydrographs for the Columbia River, Windermere Creek, and Goldie Creek are presented in Figures 3 and 4. Water flows through Windermere Lake from south to north. The largest flows into Windermere Lake between 1944 and 1996 originated from Columbia Lake, as measured at the hydrometric station located on the Columbia River near Fairmont Hot Springs (Figure 3). In the Columbia River, freshet occurs between May and September, with peak flows of approximately 70 m^3/s and mean peak flows of approximately 40 m^3/s. In the tributaries, freshet occurs annually between June and August, with peak flows as high as 2.5 m^3/s in Windermere Creek and over 1.4 m^3/s in Goldie Creek (Figure 4). Mean peak flows are 1.0 m^3/s in Windermere Creek and approximately 0.4 m^3/s in Goldie Creek. Low flows generally occur October through March (Environment Canada 2006).

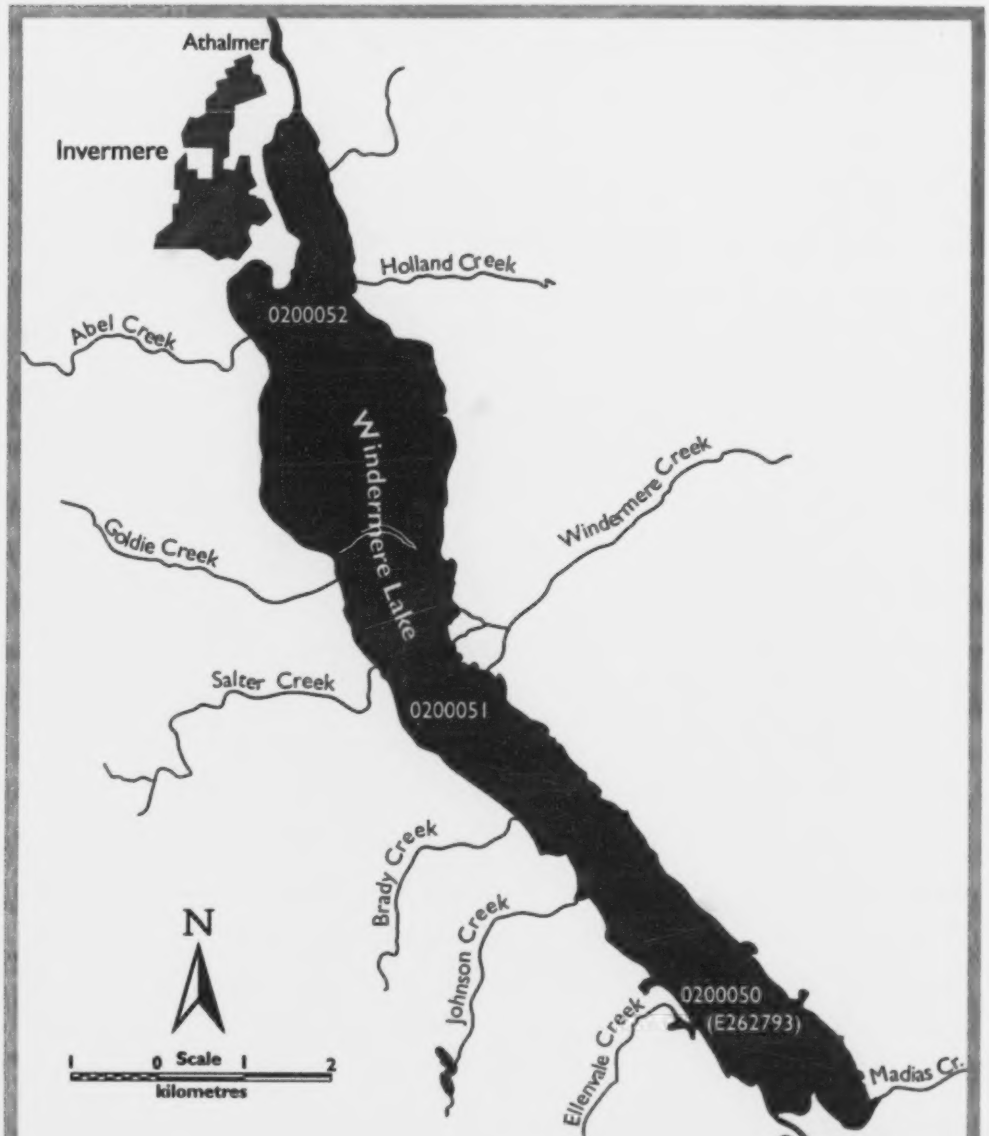


Figure 2. Locations of tributaries to Windermere Lake and water quality sampling stations.

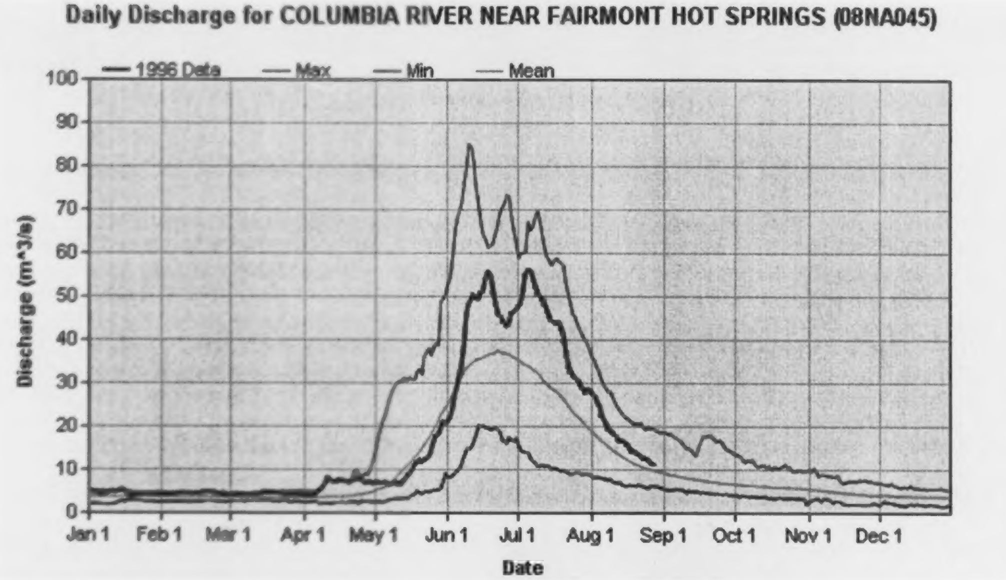
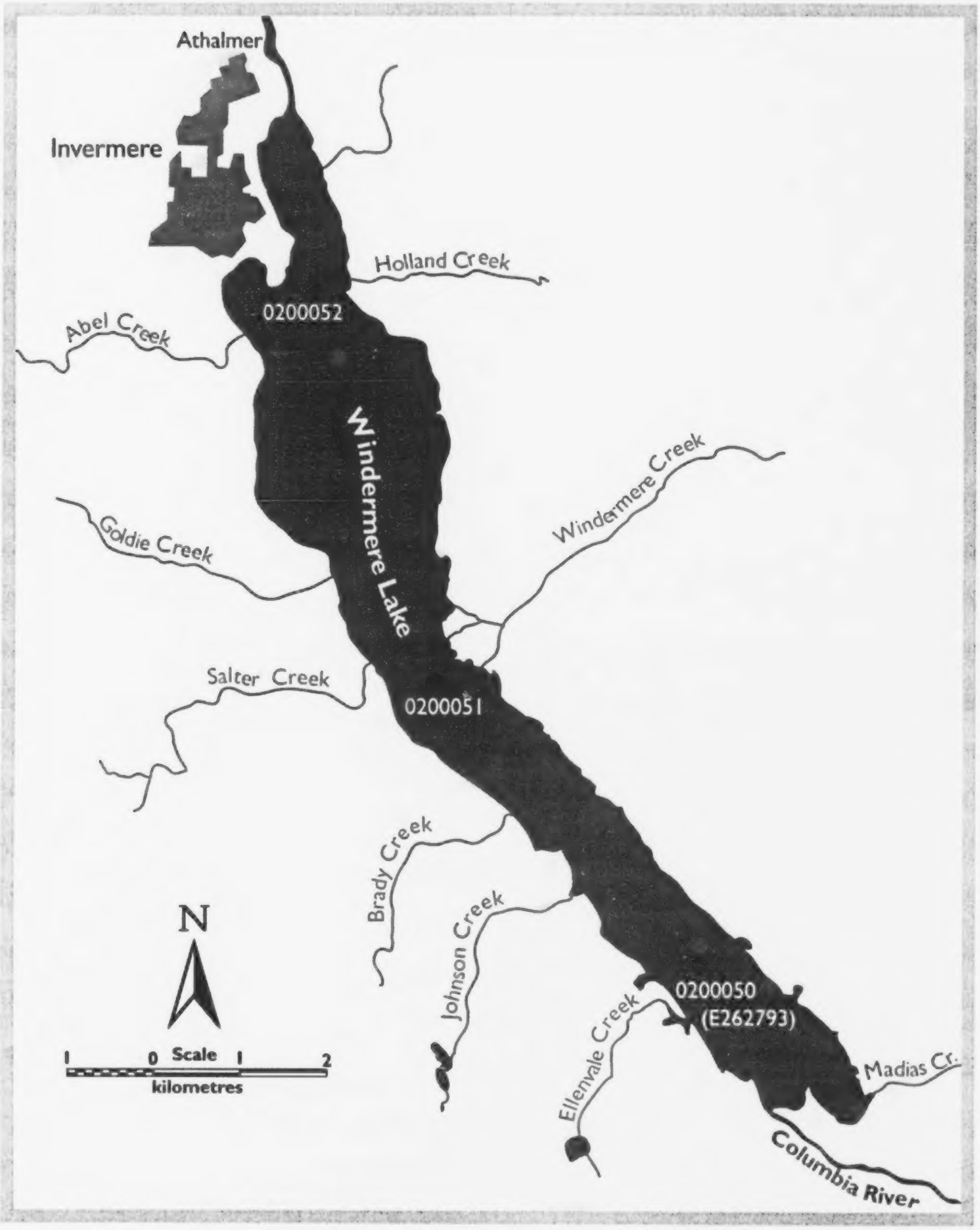


Figure 3. Flows for the Columbia River at Fairmont Hot Springs (to Windermere Lake).

3.2 Climate

The Purcell and Rocky Mountains greatly influence climate in the area. The mountains act as a barrier to the easterly movement of Pacific air masses, causing them to rise and release their moisture over the uplands. The greatest amounts of rain and snow occur on the western slopes (Department of Environment 1976). The Rocky Mountain Trench is the area between the Purcells and the Rockies, and is the warmest and driest portion of the region. Temperature and precipitation data from the Cranbrook weather station (located approximately 100 km south of Windermere Lake) are presented in Table 3. The area receives about 380 mm of precipitation, including 140 cm of snow. Temperatures average -7.5°C in January and 18.3°C in July (Environment Canada 2009).



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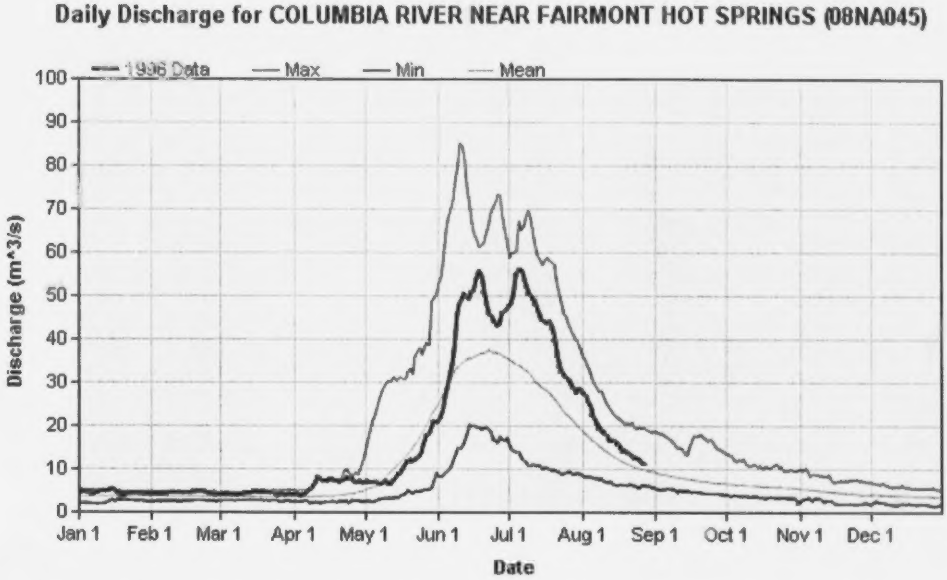

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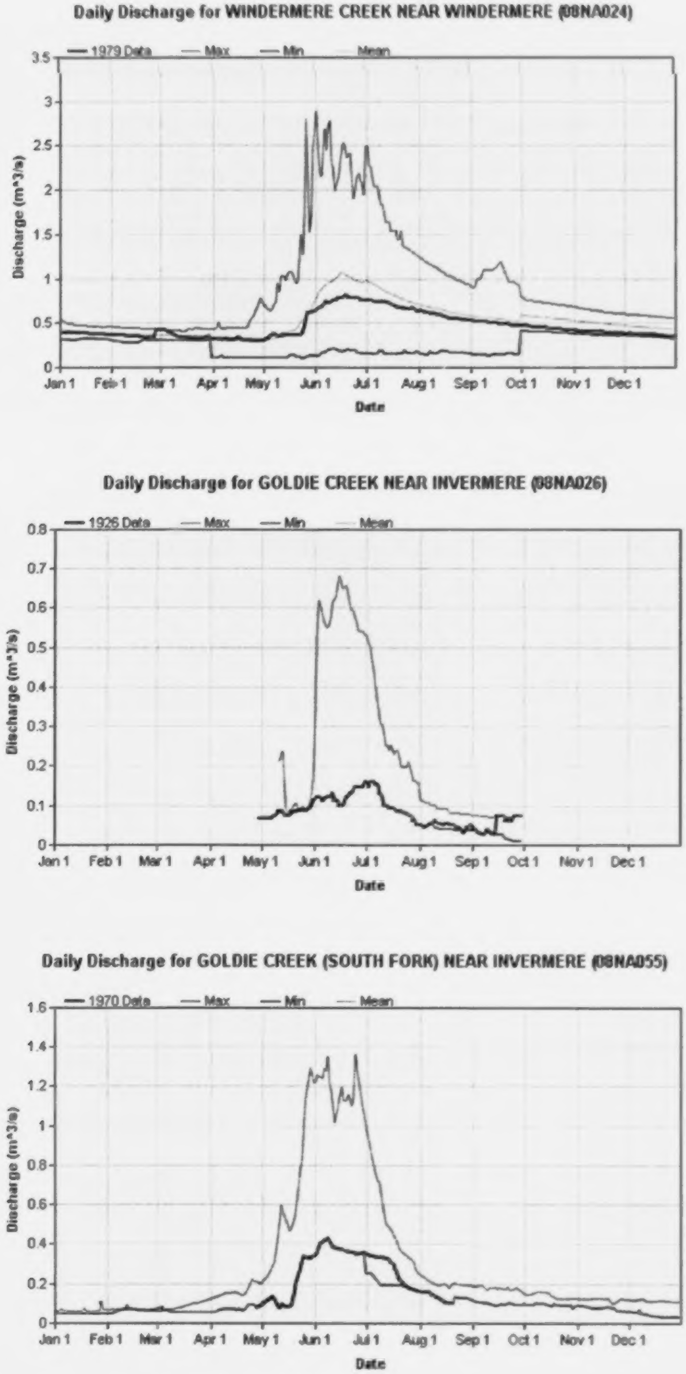

Figure 4. Flows in tributaries to Windermere Lake.

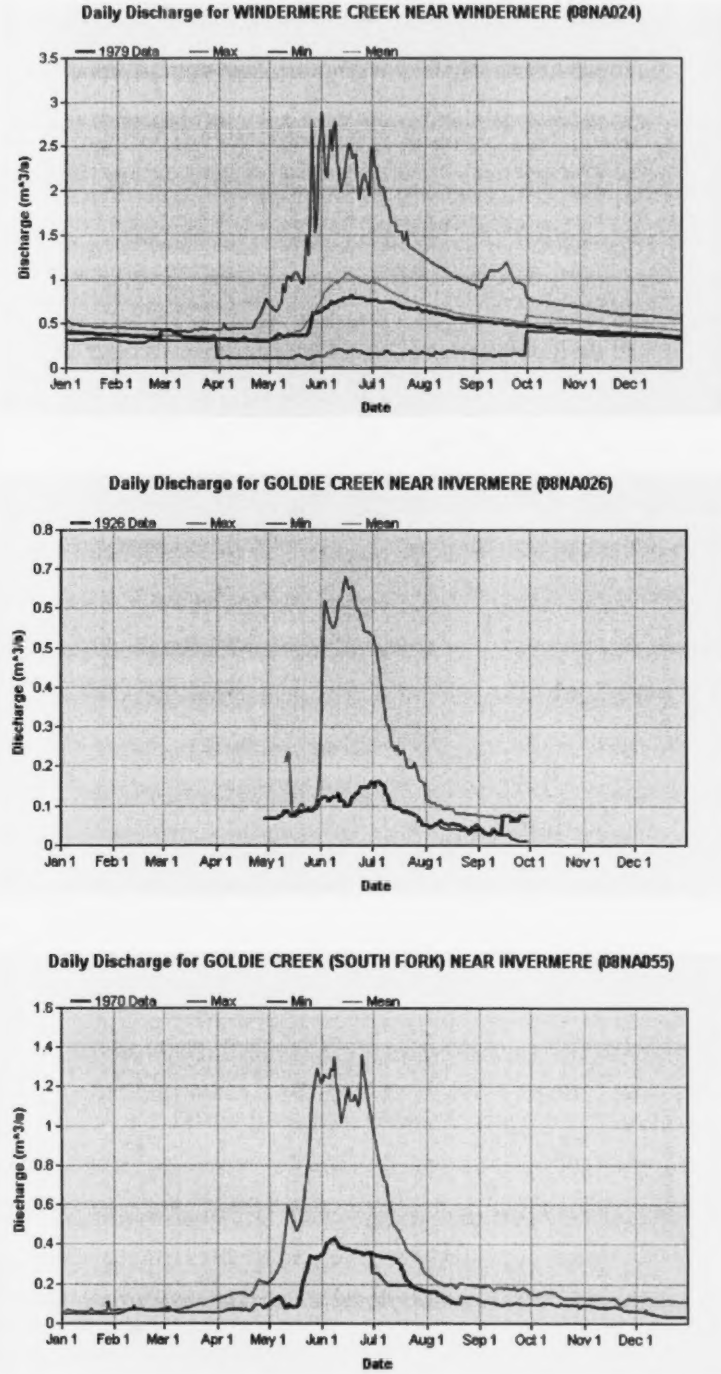

Figure 4. Flows in tributaries to Windermere Lake.

Table 3. Temperature normals from the Cranbrook weather station (1971 – 2000) (Environment Canada 2009).

Temperature:	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily Average (°C)	-7.5	-3.4	1.7	6.6	11.2	14.9	18.3	17.8	12.4	5.7	-1.6	-7
Standard Deviation	3.6	2.8	1.8	1.3	1.5	1.6	1.8	1.7	1.9	1	2.6	3.1
Daily Maximum (°C)	-3.2	1.5	7.1	12.8	17.7	21.6	25.6	25.4	19.6	11.7	2.3	-3.1
Daily Minimum (°C)	-11.8	-8.4	-3.8	0.2	4.6	8.2	10.9	10.2	5.1	-0.3	-5.5	-10.8
Precipitation:												
Rainfall (mm)	4.3	4.3	8.9	21.7	42.6	52.7	38.2	31.6	27.3	15.8	16.7	6.7
Snowfall (cm)	33	22	13.8	5.8	0.7	0	0	0	1.4	3.2	24	36
Precipitation (mm)	30.2	21.2	21.3	26.8	43.2	52.8	38.2	31.6	28.4	18.4	37.5	33.9

4. DESIGNATED WATER USES

4.1 Consumptive Water Uses

Water withdrawn from Windermere Lake is used for domestic consumption, irrigation and livestock watering. There are three community water systems that service a majority of the residences around Windermere Lake: Parr Utilities, Timber Ridge, and Windermere water intakes. The intakes provide a minimum level of treatment to the water; chlorine is added for disinfection purposes, and also reduces tastes and odours. Water license information is summarized in Table 4 (BC Ministry of Environment 2009b).

Table 4. Summary of licensed water withdrawals from Windermere Lake.

Purpose	No of Licences	Quantity[1]
Domestic	18	54.5 m^3/d
Irrigation	8	1,964,325 m^3/a
Land Improvement	3	6,167 m^3/a
Stock Watering	3	320,705 m^3/a
Waterworks	17	16593 m^3/a

1. a = annum; d = day

4.2 Fisheries Use

The fish species present in Windermere Lake include burbot (*Lota lota)*, bull trout (*Salvelinus confluentus*), Dolly Varden char (*S. malma)*, eastern brook trout (*S. fontinales*), kokanee (*Oncorhynchus nerka*), rainbow trout (*O. mykiss*), westslope (Yellowstone) cutthroat trout (*O. clarkii lewisi*), mountain whitefish (*Prosopium williamsoni*), prickly sculpin (*Cottus asper*), torrent sculpin (*C. rhotheus*), chiselmouth (*Acrocheilus alutaceus)*, largescale sucker (*Catostomus macrocheilus)*, longnose sucker (*C. catostomus)*, largemouth bass (*Micropterus salmoides)*, longnose dace (*Rhinichthys cataractae*), northern pikeminnow (formerly northern squawfish; *Ptychocheilus oregonensis)*, peamouth chub (*Mylocheilus caurinus*), pumpkinseed

(*Lepomis gibbosus)*, and redside shiner (*Richardsonius balteatus)* (BC Ministry of Environment 2009c). Although there is a high diversity of fish in the lake, overall fish counts are low (Masse and Miller 2005).

Major tributary streams entering Windermere Lake have been surveyed for fish abundance and habitat. Griffith (1994) reported that Windermere Creek was the only significant system for fisheries values, possessing major spawning and recruitment areas for kokanee. Griffith (1994) also reported that rainbow trout and bull trout were caught upstream from the kokanee spawning reach, and a good westslope cutthroat trout population was sampled 3 km upstream from Windermere Lake. The wetlands at the north and south ends of Windermere Lake provide good to excellent sport and coarse fish habitat (Urban Systems 2001).

4.3 Recreational Water Uses

Windermere Lake experiences heavy recreational use because of its large size and scenic beauty. Windermere Lake experiences more recreational use than Columbia Lake because it has more shoreline development, more public access points and more sandy beaches (Figure 5). There is limited access along the west side of the lake due to the presence of the railway line. Camping, cottaging, boating, and angling take place along the north and east sides of the lake.

Most of the properties along Windermere Lake's shoreline are privately owned. Public access points include Athalmer Beach within James Chabot Provincial Park, Invermere Beach, Windermere Beach, Kinsmen Beach, and Sunshine Ranch (Figure 5). Development on the foreshore includes private wharves, floating structures, and marinas (Masse and Miller 2005).

Heavy boat traffic occurs between July 1 and August 31 on Windermere Lake (Urban Systems 2001). Possible impacts from boating activities include increased turbidity levels, and fuel emissions and spills (Masse and Miller 2005).

Several golf courses are located in the Windermere Lake area. In general, golf courses can

affect water quality and quantity of nearby streams with the use of fertilizers and pesticides, and irrigation requirements.

Figure 5. Beaches located on Windermere Lake.

INFLUENCES ON WATER QUALITY

5.1 Forest Harvesting and Mountain Pine Beetle

Within the Windermere Lake watershed, logging is confined to numerous small areas. The Windermere Creek watershed has experienced the greatest degree of logging.

The current mountain pine beetle (*Dendroctonus ponderosae*, Hopkins) outbreak occurring in BC surpasses any bark beetle epidemic in North American history (Canadian Forest Service 2007). The status of the pine beetle epidemic within the Windermere Lake watershed ranges from areas of low to moderate severity (Canadian Forest Service 2007).

According to Dobson Engineering Ltd. (2004), dead pine dominated stands will impact hydrological processes similar to clear-cuts, resulting in increased peak flows and water yield, accelerated soil erosion, landslides, channel destabilization, and nutrient losses.

5.2 Agriculture

Agriculture in the area is not extensive. Cattle ranching is the main activity with dairy farms and the production of vegetables and small fruits making lesser contributions. Most of the cultivated land is used for hay and alfalfa production.

5.3 Recreation

Windermere Lake is a popular summer vacation destination, as well as a winter skiing haven. Recreation includes boating, fishing, sailing, sail boarding, swimming, kayaking and whitewater rafting, hiking, biking, as well as both downhill and cross country skiing.

Invermere, the commercial center for the valley, is located at the north end of Windermere Lake. In the last decade, Invermere has seen an increase in development with new

condominiums built, as well as an increase in the number and size of homes and cabins on the lake. The majority of the Windermere Lake area and Invermere population is seasonal residents, who return to the valley during the warm summer months. During the winter months, Invermere is a base for skiing and snowmobiling.

5.4 Permitted Discharges

There are no industrial, municipal, or sewage waste discharges permitted under the *Environmental Management Act* that enter Windermere Lake (Archibald 2009, personal communication).

There is an active gypsum mine operating in the Windermere Creek area; however, no permit is required for this operation.

5.5 Wildlife

Wildlife can influence water quality because warm-blooded animals can carry pathogens such as *Giardia lamblia*, which causes giardiasis or "beaver fever", and *Cryptosporidium* oocysts which cause the gastrointestinal disease, cryptosporidiosis (Warrington 1988). Warm-blooded animals excrete fecal coliform bacteria in their feces, and can cause elevated levels of this indicator of fecal contamination in water. Fecal contamination of water by animals is generally considered to be less of a concern to human health than contamination by humans because there is less risk of inter-specific transfer of pathogens. However, without specific source-tracking methods, it is impossible to confirm the origins of coliform bacteria.

Windermere Lake is a part of the Columbia Wetlands. This wetland area has over 300 species of birds and mammals and provides critical breeding grounds for bull trout, kokanee, rainbow trout and burbot. It is part of the Pacific flyway, providing refuge to 250 species of birds, including blue herons, bald eagles and osprey. It is also home to endangered species such as the painted turtle, red badger and short-eared owl (Wildsight 2007).

5.6 Mineral Claims

Presently, there are no mineral claims held within the Windermere Lake watershed.

6. WATER QUALITY ASSESSMENT AND OBJECTIVES

This report provides an assessment of water quality data collected from 2006 to 2009 in Windermere Lake. The British Columbia Approved Water Quality Guidelines were used to assess the suitability of Windermere Lake for different water uses. The *Canadian Drinking Water Quality Guidelines* (Health and Welfare Canada 2008) are used to assess the suitability of drinking water at the point of consumption after water treatment. As a minimum, the Ministry of Health requires water purveyors to disinfect all surface water prior to entering a distribution system (Drinking Water Protection Regulation 2003).

6.1 Sample Collection

Three stations in Windermere Lake were sampled for field parameters and water chemistry between 2006 and 2009. Station 0200052 in the north basin; station 0200051 at mid-lake; and station 0200050 (also known as E262793) in the south basin (Figure 2). Three public beaches (Invermere, Windermere and Althalmer beaches) were also monitored for *E.coli* and fecal coliforms as part of the monitoring program (Figure 5). In addition to the beaches and lake stations, Windermere Creek and the Columbia River inflow to Windermere Lake were also regularly sampled for both bacteriology and general water chemistry parameters. Data summaries for this period of time are provided in Appendices 2 through 4. Three water intakes (Parr, Windermere and Timber Ridge water intakes) were sampled during the winter months, but the results were not analyzed as part of this report. In 2008 sampling was also conducted on Goldie, Holland, Abel and Brady creeks to assess inputs to Windermere Lake. Results of the creek monitoring were used to aid in the interpretation of water quality results of Windermere Lake.

Water samples were collected by Wildsight, as part of the Lake Windermere Project. The sampling program was developed by Masse and Miller (2005). Surface grab samples were collected, as well as deep lake samples, approximately 0.5 m from the lake bottom, using a Van

Dorn sampler. On each sampling trip field measurements were obtained for temperature, pH, dissolved oxygen (DO) and conductivity using both YSI 600QS and YSI 550A multi-parameter meters. Samples were collected according to standard Resource Information Standards Committee (RISC) methodology (RISC 1997). Quality assurance samples were incorporated into the program and included both replicate samples and field blanks. Quality assurance audits were performed by MoE staff to ensure samples were collected in a safe manner and according to standard Ministry protocols. All samples were placed on ice and shipped to Maxxam Analytics and Cantest laboratories, both located in Burnaby, BC, within recommended holding times.

6.2 Turbidity

The original WQO for turbidity was ≤ 1 NTU (average) and 5 NTU (maximum).

Turbidity is a measure of the intensity of light scattered by particles suspended in water, and is used as an indicator of the clarity or cloudiness of water. Turbidity measurements (expressed as nephelometric turbidity units or NTUs) increase with the amount of light scattered or diffracted. Suspended particles in the water consist of silt, clay, organics, algae, and other microorganisms. These particles may carry pathogens and chemicals harmful to human health, as well as reduce light penetration, thus affecting primary and secondary productivity.

Turbidity is important to consider with respect to drinking water because suspended particles can impair the effectiveness of various disinfection processes. The water utility must use larger quantities of chlorine, or other chemical disinfectants, during periods of elevated turbidity to ensure adequate treatment of the potentially higher bacteria concentrations and to account for the absorption of chlorine by the suspended particles in the water. Water with a cloudy appearance is also aesthetically displeasing for the consumer (Caux et al. 1997). Turbid waters are also detrimental to fish populations and cause stress on the aquatic habitat in direct proportion to the magnitude and duration of each turbidity event.

Turbidity is well linked with watershed characteristics and can be greatly affected by seasonal changes, storm (rain) events, natural landslides, and human land use. Because the seasonal

changes are so pronounced, turbidity is broken into clear-flow and turbid-flow periods which are used to describe the portion of the hydrograph when suspended sediment concentrations are low (i.e., <25 mg/L) and relatively elevated (i.e., >25 mg/L) (Caux et al. 1997). The turbid-flow period generally coincides with freshet and commences when the accumulated snow pack starts to melt in the spring, resulting in increased stream flow. It ends in the summer when the snow in the watershed has melted and flows return to normal and water levels are more stable.

The timing, duration, and magnitude of the turbid-flow period are variable according to annual variations in weather. For the purposes of this assessment, the turbid-flow period is considered to be between May 1 and August 15, based on the average flows for the Columbia River at Fairmont Hot Springs (Figure 3). The clear-flow period encompasses the remainder of the year when stream flow is more stable and is not subject to fluctuations due to snow melt. For the purposes of this assessment, the clear-flow period is determined to be August 16 to April 30. During this time, turbidity values tend to be very low, with any elevated values that do occur resulting more typically from rain events and physical disturbances of stream banks.

Turbidity was measured in Windermere Creek (E231717) slightly upstream from the confluence to Windermere Lake and in the Columbia River (E262680) as it enters the lake, between 2006 and 2008 (Figure 6). Windermere Creek had the highest turbidity values, possibly due to the impact of forestry activities in that watershed, or due to impacts from the gypsum mine also located on Windermere Creek. The maximum turbidity level was 176 NTU (July 17, 2007) with other high values of 19 NTU (June 13, 2006), 20 NTU (July 12, 2006), 62 NTU (June 19, 2007), and 35 NTU (August 21, 2008). In contrast, the highest turbidity values in the Columbia River, the main source of inflow to the lake, were 6 NTU (June 19, 2007) and 4 NTU (May 28, 2007).

Turbidity was sampled at all three lake stations (Appendices 2 to 4) and is summarized in Table 5. The maximum value was 5.8 NTU at the north lake station; however, the mean value at this site was only 0.8 NTU, indicating low turbidity levels on most occasions. The mid-lake station had values of 3.5 NTU as a maximum and 1.0 NTU as a mean level, while the south lake station near the inlet of the river was higher with a maximum value of 3.8 NTU and a mean value of 1.0 NTU. The highest recorded values at the north and south ends were recorded on May 28, 2007,

while the highest values at the mid-lake were on May 14, 2008. The results measured in this study were comparable to past monitoring results for these sites.

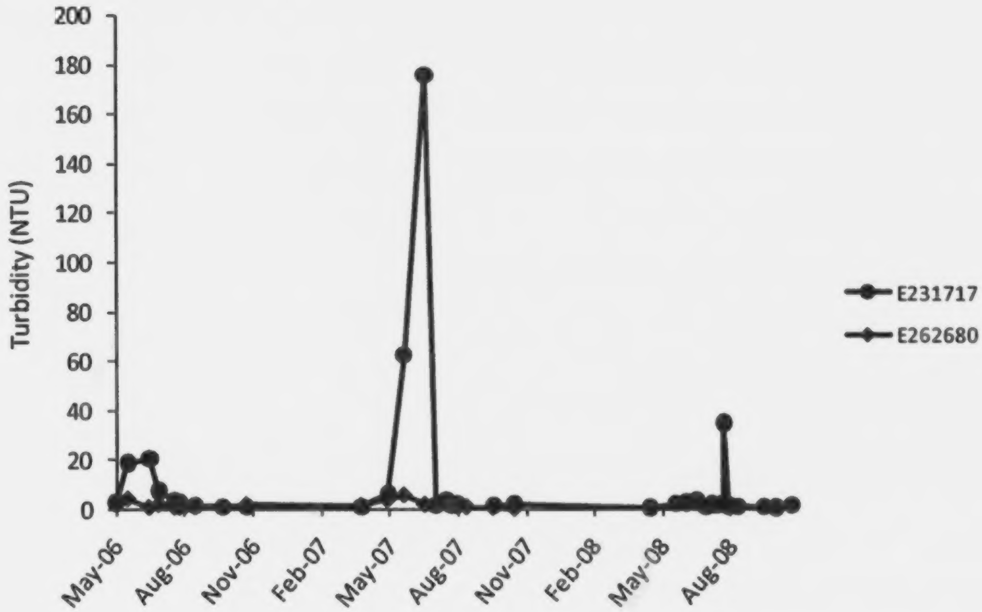

Figure 6. Turbidity measurements for Windermere Creek (E231717) and the Columbia River (E262680).

Table 5. Summary of turbidity results (NTU) for Windermere Lake, 2006 - 2009. Historical values are based on results collected in the 1970's and 1980's.

Site	Min	Max	Mean	Median	n	Historical Mean	Historical Median
0500052	0.3	5.8	0.8	0.7	32	1.0	0.6
0500051	0.3	3.5	1.0	0.8	31	1.3	0.9
E262793	0.5	3.8	1.0	1.4	32	—	—

The Health Canada (2008) guideline for treated drinking water is a target of 0.1 NTU at all times. Where this cannot be achieved, maxima of 0.3 to 3 NTU are specified, depending on the type of water treatment. The BC MoE turbidity guideline for drinking water supplies is an increase of 1 NTU over background when background is <5 NTU (which applies to Windermere Lake). It is inevitable that these guidelines will not be met in surface waters during freshet or following rain

events. Elevated turbidity in streams is common and is a naturally occurring event. When turbidity levels rise, water system operators typically take measures to safeguard against bacterial contamination such as increasing chlorine levels or issuing boil-water advisories.

McKean and Nordin (1985) established turbidity objectives for Windermere Lake (Table 1) of a maximum of 5 NTU and an average of < 1 NTU during the clear-flow period. The average concentration is based on five weekly samples collected within a 30-day period and only applies during the clear-flow period. Samples were not collected with the required frequency to calculate average values; therefore, samples from all three sample sites were pooled for each year's clear-flow period and used to calculate average concentrations. In each year, the average turbidity concentrations were less than 1 NTU. Turbidity levels were also low during the turbid-flow period, with mean concentrations ranging between 1.1 NTU (2006) and 1.5 NTU (2007). On a site-specific basis, the 95th percentile turbidity levels were 2.2 NTU at site 0500052, 2.5 NTU at site 0500051, and 3.6 NTU at site E262793.

We recommend that the water quality objective for turbidity remain unchanged for Windermere Lake: during the clear-flow period (August 16 through April 30) the maximum turbidity at any time should be $\leq$5 NTU and the mean turbidity based on a minimum of five weekly samples collected within a 30-day period during the clear-flow (non-freshet) period should be $\leq$ 1 NTU. During the turbid-flow period, we recommend a new objective: the 95th percentile turbidity should not exceed 5 NTU based on a minimum of five weekly samples collected in a 30-day period.

6.3 Temperature

Temperature is important to the quality of drinking water supplies for both health and aesthetic reasons. As water temperature increases, so does the potential for biological growth. Increased biological growth can increase chlorine demand and reduce the effects of the chlorination process. In addition, decaying organics in the water can cause taste and odour problems for the consumer. Water temperature is a critical factor for aquatic life. Fish and invertebrate's body

temperatures are, to a large extent, controlled by their environment. Water temperature directly affects activity and physiological processes of fish and aquatic invertebrates at all life stages. The capacity for water to carry dissolved oxygen, which is critical to aquatic life, is inversely related to temperature. Temperature can also affect the toxicity of other parameters, such as ammonia and increase the solubility of chemical compounds. In addition, increases in temperature can encourage the reproduction of organisms pathogenic to both fish and humans.

Water quality guidelines for temperature have been developed for several water uses (see Oliver and Fidler 2001). For drinking water supplies, it is recommended that water temperature be less than 15 °C to protect the aesthetic quality of the water. For the protection of aquatic life in lakes, the water temperature should remain within ± 1 °C of natural conditions. For the protection of aquatic life in streams, the water quality guidelines are dependent on species and life stage present (Oliver and Fidler 2001). In streams with unknown fish distributions, the water quality guideline is a mean weekly maximum temperature (MWMT) of 18 °C.

To estimate background water temperature levels for Windermere Lake, the available historical data from the 1970's and 1980's were compiled for sites 0200051 and 0200052. Windermere Lake does not thermally stratify, as noted by McKean and Nordin (1985) and evident from the data collected for the current study; therefore, daily average water temperatures were calculated from all the data available on a given date at each site. Daily averages were then pooled by month and the 95th percentile value was calculated to represent historical background conditions. It should be noted that the data was limited and these background levels should be used with caution. The results are provided in Table 6 and show that, historically, the drinking water guideline of 15 °C is likely to be exceeded between June and September. The results from the present study were compared to both the drinking water supply and aquatic life guidelines in Figure 7. Aquatic life guidelines were determined from the values listed in Table 6, plus 1°C to determine the maximum allowable temperature. The results show that temperatures continue to be well above 15 °C from June through September in Windermere Lake; therefore, the aesthetic quality of the water supply may be compromised at this time of the year.

Table 6. Historical background (95th percentile) water temperatures (°C) for Windermere Lake.

Month	Temperature	n
January		
February		
March		
April	7	2
May	14	2
June	19	8
July	20	6
August	23	8
September	15	6
October	7	7
November		
December		

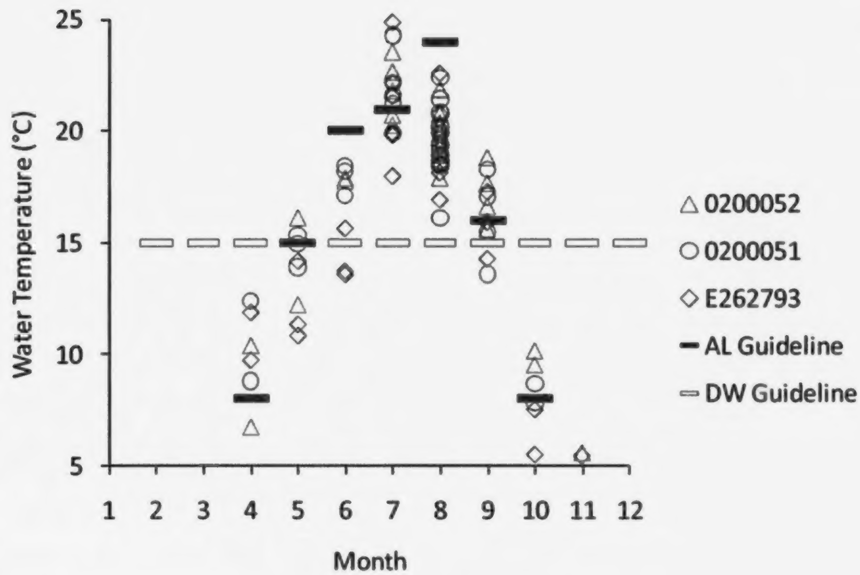

Figure 7. Monthly water temperature results (2006 – 2009) for Windermere Lake, compared to the aquatic life (AL) water quality guideline and the drinking water (DW) supply guideline.

For aquatic life, the latest results show some values below background levels in all months from June through September, however, temperatures were frequently above background levels in July and September. This is likely caused by the calculation of the background levels themselves.

Historical data (from the 1970's and 1980's) are limited and for most months background levels were based on three or four sampling dates. It is unclear how representative these background levels truly are, so monthly 95th percentile temperatures were calculated using all available data (Table 7) and these levels should be used in future assessments of Windermere Lake.

Table 7. Monthly 95th percentile water temperatures (°C) for Windermere Lake.

Month	Temperature	n
January		
February		
March		
April	12	8
May	17	11
June	20	20
July	25	24
August	23	38
September	18	17
October	10	13
November	6	8
December		

The water temperatures of the tributary streams are illustrated in Figure 8 and do not appear to be contributing significantly to the high summer temperatures measured in the lake, as temperatures were generally below 15 °C for most of the year. There was not sufficient data to calculate the MWMT (which is defined as the average of the warmest daily maximum temperatures for seven consecutive days); therefore, the results could not be compared to the water quality guideline for the protection of aquatic life. It can be assumed that most of the tributaries sampled would be below the guideline level of 18 °C with the exception of Abel Creek, which had water temperatures of 20 °C and 18 °C in July and August of 2008, respectively.

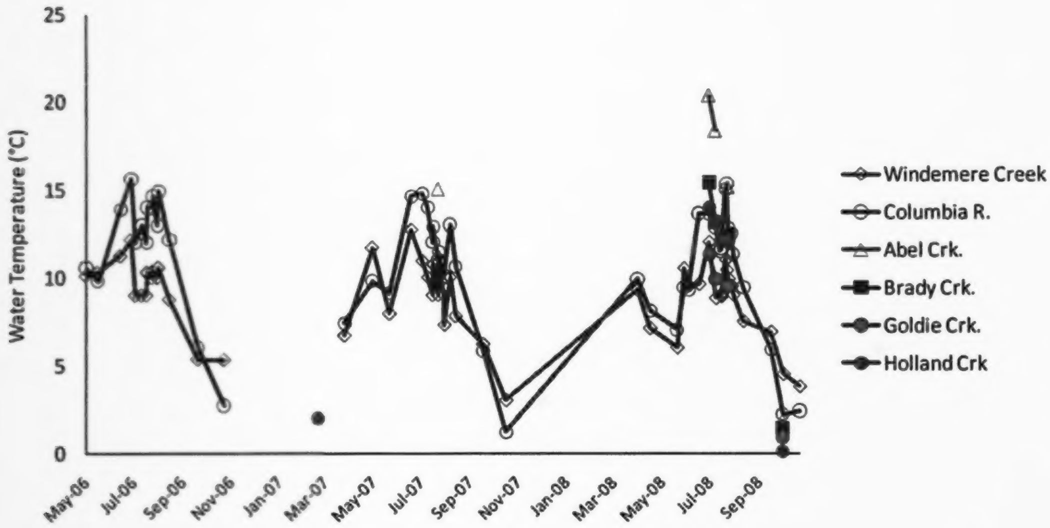

Figure 8. Water temperatures (°C) for tributary streams to Windermere Lake.

The results presented here demonstrate that the water temperatures in Windermere Lake naturally exceed the aesthetic water quality guideline for drinking water supplies and that this does not appear to be significantly influenced by the tributary streams. Proposing a water quality objective for temperature for the most sensitive designated use (i.e., drinking water) based on the guideline (15 °C) would not be useful as it will likely never be met during the summer months. **Therefore, in order to protect aquatic life, we recommend that the average water temperature (measured in the top and bottom of the water column) not exceed 20 °C, 25 °C, and 23 °C, in June, July, and August, respectively.**

6.4 Microbiological Indicators

The original WQO for fecal coliforms near water intakes is ≤ 10 MPN/100mL (90th percentile); and ≤ 200 MPN/100mL (geometric mean), or ≤ 400 MPN/100mL (90th percentile) at bathing beaches.

The microbiological quality of surface waters used for drinking and recreating is important, as contamination of these systems can result in high risks to human health and economic losses

due to closure of beaches (Scott et al. 2002). The direct measurement and monitoring of pathogens in water, however, is difficult due to their low numbers and specific growth requirements (Ishii and Sadowsky 2008). To assess the risk, resource managers commonly measure the level of fecal indicator bacteria (Field and Samadpour 2007; Ishii and Sadowsky 2008). The most commonly used indicator organisms for assessing the microbiological quality of water are the total coliforms; fecal coliforms (a subgroup of the total coliforms more appropriately termed thermotolerant coliforms as they can grow at elevated temperatures); and *Escherichia coli*, a thermotolerant coliform considered to be specifically of fecal origin (Yates 2007).

There are a number of characteristics that suitable indicator organisms should possess. They should be present in the intestinal tracts of warm-blooded animals and should not multiply outside the animal host. They should be nonpathogenic and have similar survival characteristics to the pathogens of concern. They should be strongly associated with the presence of pathogenic microorganisms and present only in contaminated samples. And finally, they should be detectable and quantifiable by easy, rapid, and inexpensive methods (Scott et al. 2002; Field and Samadpour 2007; Ishii and Sadowsky 2008).

Total and fecal coliforms have traditionally been used in the assessment of water for domestic and recreational uses. However, research in recent years has shown that there are many differences between the coliforms and the pathogenic microorganisms they are a surrogate for, which limits the use of coliforms as an indicator of fecal contamination (Scott et al. 2002). For example, many pathogens, such as enteric viruses and parasites, are not as easily inactivated by water and wastewater treatment processes as coliforms are. As a result, disease outbreaks do occur when indicator bacteria counts are at acceptable levels (Yates 2007). Additionally, some members of the coliform group, such as *Klebsiella*, can originate from non-fecal sources (Ishii and Sadowsky 2008) adding a level of uncertainty when analyzing data. Perhaps the greatest limitation of the traditional approaches is that the measurement of total and fecal coliforms does not indicate the source of contamination. Waters contaminated with human feces are generally regarded as a greater risk to human health, as they are more likely to contain human-

specific enteric pathogens (Scott et al. 2002); therefore, it is not always clear where to direct management efforts.

While the limitation of total and fecal coliforms as an indicator organism has been demonstrated, the development of alternative methods continues (Savichtcheva and Okabe 2006; Field and Samadpour 2007; Tourlousse et al. 2008; Converse et al. 2009). Until consensus is reached, the best approach may be to use *E. coli* and enterococci as acceptable alternatives to the coliform indicators in freshwater and marine systems, respectively (Scott et al. 2002). However, these are not without their limitations. *E. coli* and enterococci do not identify sources of contamination (Field and Samadpour 2007) and are not well correlated with several pathogens including *Salmonella*, *Campylobacter*, *Cryptosporidium*, *Giardia*, and viruses. They can survive, grow, and establish populations in natural environments such as fresh water lakes and streams; beach sand; soils and sediments; and plant cavities (Field and Samadpour 2007). Therefore, interpretation of results is not always straightforward (Tourlousse et al. 2008).

The objectives established for protection of recreational water uses in Windermere Lake (Table 1) were based on fecal coliforms as the indicator. Subsequently, water quality guidelines for microbiological indicators were developed by Warrington (1988) and are summarized in Table 8. It is recommended that the 90th percentile concentrations be calculated from 10 samples collected within a 30-day period and geometric means be calculated from five samples in 30 days. In BC, the recommended protocol, due to the logistics of sampling and the ability to transport samples to the laboratory in a timely manner, is to collect five weekly samples in a 30-day period, instead of the recommended 10 samples for microbiological indicators.

Data collected between 2006 and 2009 at the three main beaches, Windermere (E262679), Invermere (E207050), and Athalmer (E207051) (see Figure 5), are summarized in Table 9. The requisite number of samples (i.e., five in 30 days) was not always achieved so the data were pooled by month to determine general levels of microbiological indicators at these sites. The data suggest that, in general terms, the guidelines to protect recreational uses (i.e., the geometric means) were likely met. For example, the Windermere water intake is located approximately 500 m from Windermere Beach and the 90th percentile fecal coliform and *E. coli*

concentrations were generally below the water quality guideline to protect drinking water sources.

Table 8. Summary of the BC water quality guidelines for microbiological indicators. All guidelines are expressed in CFU (colony forming units)/100 mL.

Water Use	*E. coli*	Enterococci	Fecal Coliforms
Drinking water (disinfection only) (90^{th} percentile)	≤10	≤3	≤10
Recreation (primary contact) (geometric mean)	≤77	≤20	≤200

Table 9. Monthly geometric means (GM) and 90^{th} percentiles of fecal coliform (FC) and *E. coli* counts (CFU/100 mL) for three main beaches on Windermere Lake (2006-2009). All results are based on a minimum of five results except those denoted with an asterisk (where n = 4).

	Windermere E262679				Invermere E207050				Athalmer E207051			
	FC		*E. coli*		FC		*E. coli*		FC		*E. coli*	
Month	GM	90^{th}%	GM	90^{th}%	GM	90^{th}%	GM	90^{th}%	GM	90^{th}%	GM	90^{th}%
Jun	6	1	3*	29*	11	82	2*	6*	17	325	5	92
Jul	5	5	1	1	8	22	5	14	11	175	14	225
Aug	5	5	1	2	11	24	10	23	15	15	12	57
Sep	3	5	1	1	10	50	3	27	5	5	5	18

Both Invermere and Athalmer beaches showed elevated 90^{th} percentile concentrations for microbiological indicators. There are a number of potential explanations for the higher counts seen in the north end of the lake. Invermere Beach is the main public beach and receives high recreational use. The east shore of the lake is highly developed with several homes serviced by septic systems, which may be contributing inputs to the lake. Finally, the beaches are located in embayments which are likely not well mixed. Poor mixing, in addition to significant bird populations are likely contributing to the higher elevated fecal coliform and *E. coli* concentrations at Athalmer Beach.

Table 10 lists the geometric means where the requisite five samples in a 30-day period were collected for fecal coliforms or *E. coli*. In these cases, the guidelines for primary-contact recreation were always met.

Table 10. Summary of results for microbiological indicators (geometric means) (CFU/100 mL) at beaches with five samples in a 30-day period.

Beach	Indicator	30-day period		
		Start Date	End Date	Value
Lakeview Drive	Fecal coliforms	13 August 2007	4 Sept 2007	<5
Trethewey	Fecal coliforms	31 July 2006	28 Aug 2006	9
		30 July 2007	27 Aug 2007	<5
		6 Aug 2008	3 Sept 2008	5
		11 Aug 2008	8 Sept 2008	5
Windermere	*E. coli*	7 Aug 2007	4 Sept 2007	1
Invermere	*E. coli*	24 July 2006	21 Aug 2006	17
		31 July 2006	28 Aug 2006	21
		7 Aug 2007	4 Sept 2007	6
		13 Aug 2007	10 Sept 2007	4
		28 July 2008	26 Aug 2008	5
		6 Aug 2008	3 Sept 2008	4
Athalmer	*E. coli*	24 July 2006	21 Aug 2006	45
		31 July 2006	28 Aug 2006	34
		7 Aug 2007	4 Sept 2007	6
		13 Aug 2007	10 Sept 2007	5
		28 July 2008	25 Aug 2008	6

Given the uncertainty in linking thermotolerant (i.e., fecal) coliforms to human sources of sewage, we recommend using *E. coli* as the microbiological indicator for Windermere Lake. **To protect primary contact recreation, we propose a water quality objective for *E.coli* of $\leq$77 CFU/100 mL based on the geometric mean of results. To protect drinking water sources, we recommend the 90th percentile *E. coli* count should be $\leq$ 10 CFU/100 mL near drinking water intakes. These statistics are to be calculated from at least five weekly samples collected within a 30-day period.**

6.5 Total Phosphorus and Water Clarity

The original WQO for phosphorus is $\leq$ 0.010 mg/L (average).

Phosphorus plays a major role in nearly all phases of algal metabolism, particularly in photosynthesis. It is required in the synthesis of nucleotides, phospholipids, sugar phosphates and other compounds and is bonded in a number of essential low molecular weight enzymes and vitamins (Wetzel 1983).

Phosphorus is least abundant in relation to other required nutrients, and therefore, usually limits primary productivity in lakes (Brönmark & Hansson 1998). However, to raise algal biomass, additions of both phosphorus and nitrogen are usually required (Kallf 2002). The most available fraction of phosphorus for direct uptake by aquatic primary producers is the dissolved inorganic form, orthophosphate (ortho-P), which is also referred to as soluble reactive phosphorus (Nordin 1985). More than 90% of phosphorus occurs as biologically unavailable organic phosphates and cellular constituents within the biota (Wetzel 1983), while orthophosphate is usually less than 5% of all phosphorus. Other fractions include organic phosphorus and particulate phosphorus which are transformed to more available forms at rates dependent on microbial action, environmental conditions, the origin of material, kinetics, and water residence time. In lakes with a short water residence time, there is a higher rate of flushing which limits the amount of organic phosphorus that is transformed to inorganic phosphorus (Nordin 1985).

Phosphorus is measured as total phosphorus (TP), orthophosphate, and total dissolved phosphorus (TDP). Total phosphorus consists of orthophosphate, total dissolved phosphorus and particulate phosphorus (>0.45 µm in diameter), which can be both organic and mineral in origin. The total dissolved phosphorus fraction consists of orthophosphate and a fraction of dissolved organic phosphorus from the breakdown of biotic material and polyphosphates. In most lakes (except those with heavy suspended sediment loads), total phosphorus is the best estimate of biologically available phosphorus (Nordin 1985).

Phosphorus turnover rates vary seasonally and can be very rapid during the summer when demand for plant growth is high and external inputs are lower. During winter and spring, external phosphorus loading and sedimentation is high while internal loading is low. During the summer months, the rate of phosphorus release from the sediments is greater and sedimentation from the water column (organic phosphorus from algae as well as iron complexes) increases through the season. There can also be some vertical redistribution of phosphorus released from the sediments across the thermocline (Environment Canada 2003).

The BC water quality guideline for total phosphorus in lakes is a maximum of 10 µg/L to protect drinking water sources and a range of 5 µg/L to 15 µg/L to protect aquatic life. The objective set for Windermere Lake is a maximum of 10 µg/L (the mean of three samples collected at the top, middle, and bottom of the water column at spring overturn) to protect drinking water sources (McKean and Nordin 1985).

Spring phosphorus concentrations for Windermere Lake are listed in Tables 11a through 11c. All results were below the current water quality objective indicating phosphorus levels are not a concern in Windermere Lake at this time. With few exceptions, phosphorus concentrations remained low at all sites throughout the year (Appendices 2 through 4). On August 14, 2007, the total phosphorus concentration in bottom waters was 38 µg/L, but this may have been caused by sediments being included in the sample. On September 11, 2007, total phosphorus concentrations were elevated at all sites (25 µg/L, 36 µg/L, and 13 µg/L at the south, mid, and north lake stations, respectively). It is unclear as to what may have caused the increase but this appears to be an exception to the conditions typical of Windermere Lake. During the period of study, phosphorus concentrations were similar throughout the water column. This illustrates the lack of thermal stratification in Windermere Lake and suggests that internal phosphorus loading (common in many lakes) may not be an issue here.

Table 11a. Spring phosphorus results (μg/L) for Windermere Lake at site E262793 in the south basin.

	Total P			Ortho-P			Total Dissolved P		
Date	Top	Bottom	Avg.	Top	Bottom	Avg.	Top	Bottom	Avg.
17-May-06	4	3	3.5	5	6	5.5	3	2	2.5
23-Apr-07	5	5	5	4	4	4	5	5	5
14-May-08	5	6	5.5	1	1	1	4	5	4.5
15-Apr-09	6	—	6	2	—	2	6	—	6

Table 11b. Spring phosphorus results (μg/L) for Windermere Lake at site 0200051 in the mid-lake basin.

	Total P			Ortho-P			Total Dissolved P		
Date	Top	Bottom	Avg.	Top	Bottom	Avg.	Top	Bottom	Avg.
17-May-06	3	4	3.5	5	6	5.5	4	2	3
23-Apr-07	4	—	4	5	—	5	5	—	5
14-May-08	1	—	1	7	—	7	6	—	6
15-Apr-09	2	—	2	4	—	4	4	—	4

Table 11c. Spring phosphorus results (μg/L) for Windermere Lake at site 0200052 in the north basin.

	Total P			Ortho-P			Total Dissolved P		
Date	Top	Bottom	Avg.	Top	Bottom	Avg.	Top	Bottom	Avg.
17-May-06	4	—	4	—	—	—	—	—	—
23-Apr-07	10	7	8.5	4	4	4	4	4	4
14-May-08	3	8	5.5	1	—	1	5	—	5
15-Apr-09	4	6	5	1	1	1	4	5	4.5

Changes in phosphorus concentration over time were also assessed. Data are available for the mid-lake (0200051) and north lake (0200052) stations. Spring concentrations over time are illustrated in Figure 9 and show that phosphorus concentrations have remained quite similar, if not declined since the 1970's. Over the past 20 years, total phosphorus concentrations have consistently met the water quality objective for the protection of drinking water sources, and

have generally been within the guidelines for the protection of aquatic life. This suggests that developmental pressures have not influenced the lake water quality in this regard. This is likely the result of the large flows through the lake which do not allow phosphorus to accumulate, and/or the relatively high dissolved oxygen concentrations in the lake which prevent phosphorus that is bound to the sediments from being released into the water column during anoxic conditions (i.e., internal phosphorus loading). It is not clear as to whether or not there is any internal phosphorus loading occurring during winter when Windermere Lake is frozen as no samples were collected during this time period. It is possible that this is not an issue due to continuous water movement. At the same time, because stratification of the water column does occur in winter when the lake is frozen (McKean and Nordin 1985), internal loading during the winter may explain the higher total phosphorus concentrations measured between 1972 and 1987.

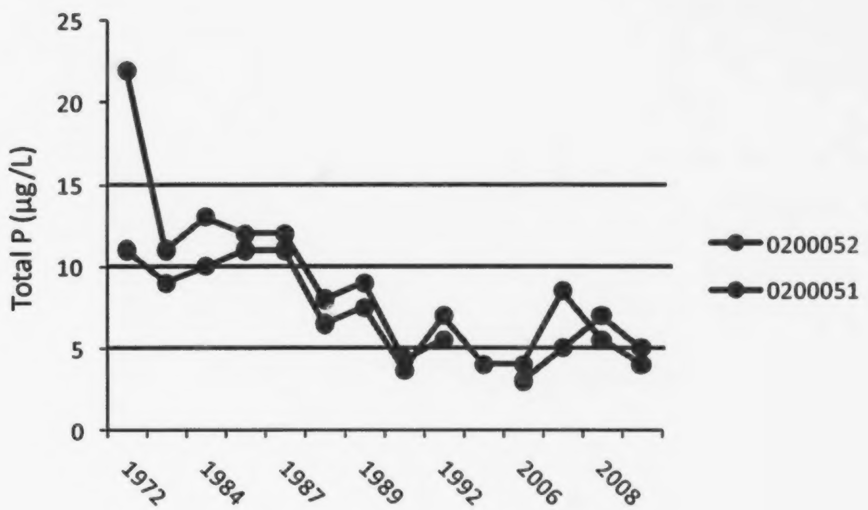

Figure 9. Spring phosphorus concentrations (µg/L) in Windermere Lake over time in the north (0200052) and mid-lake (0200051) basins. Concentrations are the mean of samples taken at the top and bottom of the water column, when available, or the surface only. The existing water quality objective for the protection of drinking sources in Windermere Lake is represented with the red line (10 µg/L) and the water quality guideline for the protection of aquatic life (5 µg/L – 15 µg/L) is represented with the green lines.

We recommend that, due to the relatively low phosphorus concentrations in the lake, the existing total phosphorus objective of a maximum of 10 µg/L be maintained. Monitoring to check for attainment of the objective should take place as soon as possible after ice-off to determine if any internal phosphorus loading is occurring over winter.

Water clarity is measured using a Secchi disc, which is lowered into the water until no longer visible from the surface. Secchi depths provide a simple, standardized measure of water clarity that can be used to indicate changes in water quality, as water clarity decreases with increasing color, suspended sediments, or algal abundance.

For Windermere Lake, the bathymetry of the lake (Appendix 1) can limit the measurements to the total depth of the water at the sample location. This is evident for sites E262793 and 0200051 at the south and mid-lake locations, respectively. The maximum depths at these two locations are about 3 m and 4 m, respectively, while the depth can be over 7 m in the north basin (0200052). Maximum Secchi depths from south to north were 3.3 m, 3.8 m, and 6.9 m, while the average Secchi depths were 2.3 m, 1.4 m, and 5.3 m. **These results indicate good water clarity in Windermere Lake; therefore, we do not recommend an objective for this variable at this time.**

6.6 Total Organic Carbon

Most water contains organic matter that can be measured as total organic carbon (TOC). The TOC in water can be a useful indication of the degree of pollution, especially when upstream and downstream comparisons can be made relative to potential pollution sources. TOC consists of dissolved organic carbon (DOC) and particulate organic carbon (POC). DOC is composed primarily of two categories of substances: nonhumic substances, which include carbohydrates, proteins, fats, and other low molecular weight compounds; and humic substances, which consist of colored hydrophilic acidic complexes. POC consists of organic input from the drainage basin (e.g., leaf litter) and from within lakes and streams (Moore 1998).

Disinfection has been used since the beginning of the 20th century to eradicate and inactivate pathogens in raw water (Sadiq and Rodriguez 2004). While disinfectants reduce the microbial risk, they can also produce an unintended health risk in the formation of disinfection by-products (DBPs) which are produced from the reaction between the disinfectant and natural organic matter (including TOC) in the source water (Richardson 2003; Sadiq and Rodriguez 2004; Charrois and Hrudey 2007). Currently, the occurrence of DBPs in drinking water is a major concern because they are potentially carcinogenic and toxicological studies suggest they may also cause reproductive and developmental complications (Rodriguez et al. 2007). Ingestion is not the only route of exposure to DBPs; inhalation and dermal absorption through showering, bathing and swimming are also pathways for human intake of DBPs (Richardson 2003). The BC water quality guideline for TOC to protect drinking water sources (minimize the production of DBP's) is 4 mg/L in systems that use chlorination for disinfection (Moore 1998).

TOC was not part of the regular monitoring program, hence, was measured only twice in this study (at the north basin site) in an attempt to track slightly elevated TOC readings from tributary streams. Concentrations were less than 2 mg/L, but higher concentrations have been measured in the past. More data is needed to properly characterize this variable. **In the meantime, to protect drinking water quality in Windermere Lake we recommend an objective for total organic carbon (near water intakes) of a maximum of 4 mg/L TOC at any time.**

6.7 Nitrogen

Nitrogen, along with phosphorus, carbon and hydrogen, is one of the major constituents of the cellular protoplasm of organisms and plays a key role in the productivity of freshwaters (Wetzel, 1983). Nitrogen occurs mainly in the amino acids and proteins of organisms (Brönmark and Hansson, 1998) and is also involved in the functions of nucleotides, nucleic acids, chlorophyll and coenzymes. Nitrogen limitation in lakes is less common than P limitation because of the potential for fixation of atmospheric N by cyanobacteria (Nordin, 1985).

The aquatic nitrogen cycle is a balance of nitrogen inputs and nitrogen losses from an aquatic environment. Nitrogen inputs to aquatic systems include atmospheric (particulate fallout and precipitation), nitrogen fixation in both the water and the sediments, and inputs from both groundwater and surface water. Nitrogen losses occur through outflows from the basin, nitrogen gas (N_2) losses to the atmosphere, and sedimentation of inorganic and organic nitrogen containing compounds (Wetzel 1983).

Nitrogen occurs in the environment in a number of forms; the most important in primary production are the inorganic forms ammonia and nitrate (Nordin 1985). Ammonia is the most reduced inorganic form found in water and exists in two states in equilibrium, depending on environmental conditions: ammonia (NH_3) and ammonium (NH_4^+) (Nordin & Pommen 1986). Ammonia is the most favourable form of nitrogen for cell uptake (Brönmark & Hansson 1998); however, the preference for either ammonia or nitrate (NO_3^-) will be dependent on the algal species (Nordin 1985). Ammonia is usually low in aerobic waters because of the utilization by plants in the photic zone (Wallace 2002) and nitrification to nitrate. Inorganic nitrogen can also be absorbed to sediments and released when conditions in the water change. Other forms of nitrogen include nitrite (NO_2^-), which can be very toxic to aquatic life and humans, but is an unstable intermediate form of nitrogen and generally not present in large quantities in undisturbed lakes; dissolved organic nitrogen usually in the form of polypeptides and complex organics; and, particulate organic nitrogen present as phytoplankton, zooplankton and detritus. Dissolved organic nitrogen may be biologically available as amino acids and is quickly utilized by bacteria.

The water quality guideline for nitrate in source drinking waters is 10 mg/L (Nordin and Pommen 1986). For the protection of freshwater aquatic life, the 30-day average concentration should not exceed 3.0 mg/L and the maximum concentration at any time is 31.3 mg/L (Meays 2009). The nitrite guideline to protect aquatic life is based on chloride concentrations (see Nordin and Pommen 1986); for the protection of drinking water sources, the guideline is 1.0 mg/L. Ammonia guidelines to protect aquatic life are pH and temperature dependent (see Nordin and

Pommen 1986). There are no water quality guidelines for total nitrogen.

Total nitrogen, nitrate+nitrite, and ammonia results are summarized in Table 12. Total nitrogen concentrations in Windermere Lake were not excessive and were typical of healthy lakes. Nitrate and nitrite were measured together; however, the combined measurement was well below guideline levels for nitrate (drinking water and aquatic life) and nitrite (drinking water). Chloride was not measured as part of this study, so a direct comparison of these results to the nitrite guidelines for the protection of aquatic life cannot be done. Historical data show chloride levels less than 2 mg/L so the appropriate guideline levels would be 60 µg/L for acute exposures and 20 µg/L for chronic exposures. The results of this study show levels generally well below these levels. The only possible exceedance would be a concentration of 127 µg/L measured on May 14, 2008. As nitrate + nitrite measurements generally consist mostly of nitrate, this one result is not of concern.

Table 12. Summary of total nitrogen (TN), nitrate+nitrite (NO_3+NO_2), and ammonia (NH_4) results (µg/L) for Windermere Lake (2006 – 2009).

Variable	Site	Mean	SD	Min	Max	n
TN	South basin	124	43	40	245	28
	Mid-lake	148	50	80	280	30
	North basin	157	59	70	290	32
NO_3+NO_2	South basin	12	15	<2	48	28
	Mid-lake	12	24	<2	127	29
	North basin	5	6	<2	35	32
NH_4	South basin	8	7	<5	38	28
	Mid-lake	8	6	<5	25	27
	North basin	14	12	<5	14	32

Ammonia water quality guidelines decrease with increasing temperature and pH. Assuming

worst-case conditions (e.g., pH = 9.0, temperature = 20 °C), which do occur in Windermere Lake, the maximum allowable ammonia concentration would be 750 μg/L and the average concentration would be 100 μg/L. The results of this study show ammonia concentrations well below this level. **The low levels of nitrogen shown in this study indicate these variables are not of concern at this time, therefore, no objective is recommended at this time.**

6.8 Dissolved Oxygen

Dissolved oxygen (DO) is a measure of the amount of oxygen dissolved in natural surface waters and is dependent on temperature, salinity, turbulence and mixing, and atmospheric pressure. The capacity of water to hold oxygen in solution is inversely proportional to water temperature, therefore, lower DO concentrations can be expected during warmer seasons. The amount of organic material in a lake can also influence DO concentrations as oxygen is consumed during the decomposition of these materials on the lake bottom. DO concentrations in surface water can range from a low of 0 mg/L to a high of 15 mg/L (supersaturation). Natural flowing surface waters generally have a value of less than 10 mg/L.

The DO water quality guideline for the protection of aquatic life is an instantaneous concentration in the water column of 5 mg/L and a 30-day average concentration of 8 mg/L (Truelson 1997). Windermere Lake is not known to have suitable sites for potential beach spawning species, such as kokanee and mountain whitefish (McPherson and Hlushak 2008); therefore, the other DO water quality guidelines are not applicable. There are no guidelines established for potable water; however, for aesthetic reasons, water saturated with DO is preferable because at low DO concentrations water can have elevated levels of dissolved iron and manganese, resulting in an undesirable taste.

Historical DO concentrations and results from the current study are illustrated in Figure 10. The results presented are daily means of available data from all sites and depths. Temperature (Section 6.3) and DO measurements show that Windermere Lake has a well mixed water column justifying the pooling of data. Oxygen levels in the lake were generally quite good, with all but

one measurement exceeding the 5 mg/L instantaneous minimum value. This was for a measurement of about 2 mg/L made at the bottom of the lake at the north lake station (0200052) on September 12, 2006. It is unclear whether this is a correct result or a sampling error, as bottom DO concentrations at this site in 2008 were relatively high throughout the year (7 mg/L – 14 mg/L). DO concentrations in June and July of 2008 were between 6 mg/L and 8 mg/L, suggesting that concentrations below guideline levels can occur.

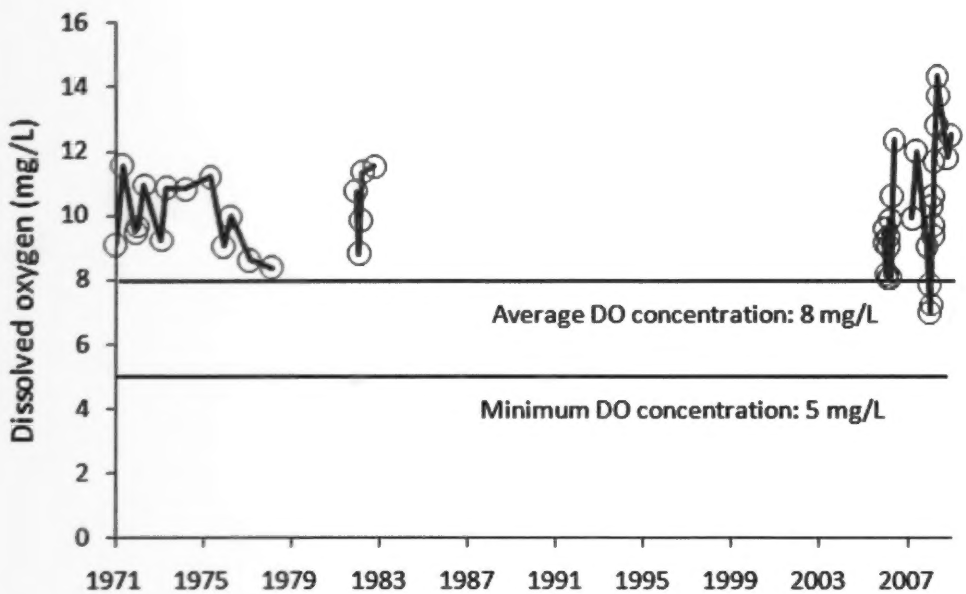

Figure 10. Mean dissolved oxygen concentrations (mg/L) in Windermere Lake. Red lines represent water quality guidelines.

DO levels seem to reflect natural conditions at this time, with concentrations being lower during the hot summer months when the ability of the water to hold oxygen is decreased. Due to the increased levels of development around Windermere Lake, an objective for DO is proposed. **The recommended objective is that the minimum (instantaneous) dissolved oxygen level should be ≥5 mg/L and the 30-day mean should be ≥ 8 mg/L to protect aquatic life.**

6.9 pH

pH is a measure of hydrogen ion concentration and indicates the balance between the acidic and basic nature in water. The pH scale runs from 0 to 14 with 7 being neutral, above 7 is basic, and below 7 is acidic. pH levels can influence aquatic species composition, the availability of nutrients, and the relative toxicity of trace elements. The pH of surface waters can be influenced by anthropogenic activities leading to acid precipitation (e.g., fossil fuel combustion) and acid rock drainage resulting from mining activities.

The water quality guideline for pH is set at 6.5 to 8.5 to protect water supplies. This range helps control corrosion in the distribution system by decreasing the solubilization of heavy metals from steel and ductile iron distribution pipes; decreasing the precipitation of carbonate salts in the pipes; and maximizing the chlorination effect. The water quality guideline to protect aquatic life is a pH range of 6.5 to 9.0 (McKean and Nagpal 1991).

The pH data for Windermere Lake between 2006 and 2008 are summarized in Table 13. These results are comparable to the levels reported by McKean and Nordin (1985) of 8.4, 8.5, and 8.4 for the south basin, mid-lake basin, and north basin, respectively. The pH of water in Windermere Lake is likely natural in origin and does not appear to be influenced by human sources. **Since there are no apparent sources in the watershed that could alter the pH significantly, we do not recommend an objective for pH at this time.**

Table 13. Summary of pH data for Windermere Lake, 2006 – 2008.

	South basin (E262793)			Mid-lake (0200051)			North basin (0200052)		
	2006	2007	2008	2006	2007	2008	2006	2007	2008
Mean	8.1	8.7	8.4	8.4	8.8	8.6	8.3	8.8	8.7
SD	0.2	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.4
Min	7.8	8.2	8.1	7.9	8.3	8.1	8.2	8.3	8.3
Max	8.5	9.0	8.8	8.7	9.0	9.1	8.8	9.1	9.2
n	10	10	11	11	10	11	9	11	12

6.10 Specific Conductance

Specific conductance is a measurement of the ability of water to conduct an electric current and is dependent on the concentration of ions in the water. Ions include dissolved inorganic materials including calcium, magnesium, sodium, potassium, and anions of carbonate, bicarbonate, chloride, sulphate and nitrate. The specific conductance of water generally increases with the concentration of dissolved solids although not necessarily in direct proportion. Water temperature can also influence specific conductance with warmer water having higher specific conductivity. Specific conductivity is reported in terms of microsiemens per centimeter (µS/cm). Natural waters vary between 50 µS/cm and 1,500 µS/cm. In BC, coastal freshwater systems have a specific conductance of approximately 100 µS/cm, while interior systems can range up to 500 µS/cm, depending on the geology of the drainage basin.
It is possible to establish a relationship between specific conductance and the concentration of total dissolved solids (TDS) in a specific waterbody, therefore, specific conductance has been used as an alternative measure for TDS.

The concentration of dissolved solids, and therefore the specific conductance, varies temporally. Spring snowmelt or summer storm events may dilute the ionic concentration resulting in lower specific conductance values during increased flow levels. In contrast, warm summer temperatures or groundwater input to streams in winter can result in higher specific conductance. Therefore, water level and specific conductance tend to be inversely related. However, in situations such as landslides or runoff from anthropogenic sources (e.g., mining, road salts, and industrial and municipal effluents), where high levels of dissolved and suspended solids are introduced to a waterbody, specific conductance levels tend to increase. As such, significant changes in specific conductance can be used as an indicator of impacts on water quality from both land use activities and natural occurrences.

Due to its natural variability, there are no water quality guidelines for specific conductance. In terms of drinking water quality, high TDS and specific conductance levels are aesthetically

unpleasing. There is an aesthetic drinking water guideline of 500 mg/L for TDS for finished water (Health and Welfare Canada 2008), and would be an appropriate guideline value for source waters used for drinking that receive no treatment for dissolved solids removal. This equates to a specific conductance of approximately 700 µS/cm (BC Ministry of Environment 1997).

A summary of specific conductance measurements taken in Windermere Lake between 2006 and 2008 is provided in Table 14. Specific conductance was lower at the south lake station than the mid-lake and north lake stations and is consistent with previously reported mean levels of 240 µS/cm, 250 µS/cm, and 260 µS/cm for the south, mid-lake, and north lake stations, respectively (McKean and Nordin 1985). **The levels reported in the current study suggest that specific conductance is typical of natural levels and has remained fairly consistent over time. In addition, TDS concentrations appear to be within an acceptable range for source drinking water. Therefore, no objective for specific conductance is recommended at this time.**

Table 14. Summary of specific conductance data (µS/cm) for Windermere Lake, 2006 – 2008.

	South basin (E262793)			Mid-lake (0200051)			North basin (0200052)		
	2006	2007	2008	2006	2007	2008	2006	2007	2008
Mean	246	250	261	274	270	275	302	293	276
SD	44	40	53	62	71	104	76	59	65
Min	170	180	170	190	210	190	240	230	230
Max	320	330	340	370	490	540	573	420	430
n	21	20	16	16	15	10	20	22	15

6.11 Sulphate

The sulphate water quality guideline for the protection of drinking water is 500 mg/L (aesthetic objective) and 100 mg/L for the protection of aquatic life (Singleton 2000). Windermere Lake receives inputs of sulphur from the upstream hotsprings and sulphate from gypsum ($CaSO_4$) deposits in Windermere Creek (McKean and Nordin 1985). During the sampling period, the

average sulphate concentration measured in Windermere Creek was 332 mg/L (SD = 43 mg/L, n = 36). Concentrations of sulphate in Windermere Lake were below the guideline levels on all sampling occasions, except May 20, 2008, when 120 mg/L of sulphate was recorded in the surface sample at the mid lake station (0200051). On April 28, 2008, the closest sampling date in Windermere Creek, the sulphate concentration was the highest measured at 430 mg/L, showing elevated inputs to Windermere Lake prior to the May 20, 2008, sample. Furthermore, throughout the sampling period, sulphate levels were highest at the mid-lake station and lowest at the south basin station, suggesting an influence from Windermere Creek which enters Windermere Lake at the mid-lake station. **Although the data indicate that Windermere Creek is a source of sulphate to Windermere Lake, it does not appear to be impacting the lake at this time, therefore no objective is proposed. Monitoring for sulphate levels should, however, be included in future monitoring programs for Windermere Lake.**

6.12 Summary of Proposed and Updated Water Quality Objectives

The water quality objectives recommended in this report are summarized in Table 15. The objectives apply to all areas of Windermere Lake unless otherwise noted.

Table 15. Proposed water quality objectives for Windermere Lake.

Parameter	Site	Objective
Turbidity[1]	0200051, 0200052, E262793	≤5 NTU (maximum)
		≤1 NTU (average)
	0200051, 0200052, E262793	5 NTU (95th percentile)
Temperature[2]	0200051, 0200052, E262793	20 °C June (average)
		25 °C July (average)
		23 °C August (average)
E. coli[3]	Bathing Beaches; Drinking Water Intakes	≤77 CFU/100 mL (geo. mean)
		≤10 CFU/100 mL (90th percentile)
Phosphorus[4]	0200051, 0200052, E262793	10 ug/L (maximum)
TOC[5]	Near Drinking Water Intakes	4 mg/L (maximum)
DO	0200051, 0200052, E262793	≥5 mg/L (instantaneous minimum)
		≥8 mg/L (average)

1. During the clear-flow period (August 16 through April 30) maximum turbidity at any time should be ≤5 NTU and mean turbidity (based on a minimum of five weekly samples collected within a 30-day period) during the clear-flow (non-freshet) period should be ≤ 1 NTU. During the turbid-flow period (May 1 through Aug 15), the 95th percentile turbidity should not exceed 5 NTU (based on a minimum of five weekly samples collected in a 30-day period).
2. For the protection of aquatic life, the average water temperature (measured in the top and bottom of the water column) should not exceed 20 °C, 25 °C, and 23 °C, in June, July, and August, respectively.
3. To protect primary-contact recreation, the geometric mean for *E. coli* should be ≤ 77 CFU/100 mL. To protect drinking water sources, the 90th percentile *E. coli* count should be ≤ 10 CFU/100 mL near drinking water intakes. These statistics are to be calculated from at least five weekly samples collected within a 30-day period.
4. Monitoring to check for attainment of the objective should take place as soon as possible after ice-off to determine if any internal P loading is occurring over winter.
5. To protect drinking water quality total organic carbon (near water intakes) should not exceed a maximum of 4 mg/L at any time.

7. MONITORING RECOMMENDATIONS

The monitoring recommendations to determine if water quality objectives are being achieved are summarized in Table 16. This program reflects conditions at the time of this assessment. Other monitoring activities may be undertaken to address future questions related to the water quality of Windermere Lake.

Table 16. Recommended monitoring to check attainment of water quality objectives.

Parameter	Site	Depth	Frequency and Timing
Turbidity, temperature, conductivity, pH, DO	0200051, 0200052, E262793		Five times (weekly) in 30 days during the turbid-flow period (May 1 – August 15). Five times (weekly) in 30 days during the clear-flow period (August 16 – April 30).
E. coli	Bathing beaches (Athalmer, Invermere and Windermere beaches minimum)		Weekly June 15 – August 31
	Water intakes		Weekly June 15 – August 31
Total and dissolved phosphorus	0200051, 0200052, E262793	Surface and 1 m above the bottom	Monthly (June – August)
TOC	Near water intakes		Monthly (June – August)
Dissolved sulphate	0200051	Surface and 1 m above the bottom	Monthly (June – August)
Total nitrogen, nitrite, nitrate, chloride	0200051, 0200052, E262793	Surface and 1 m above the bottom	Monthly (June – August)

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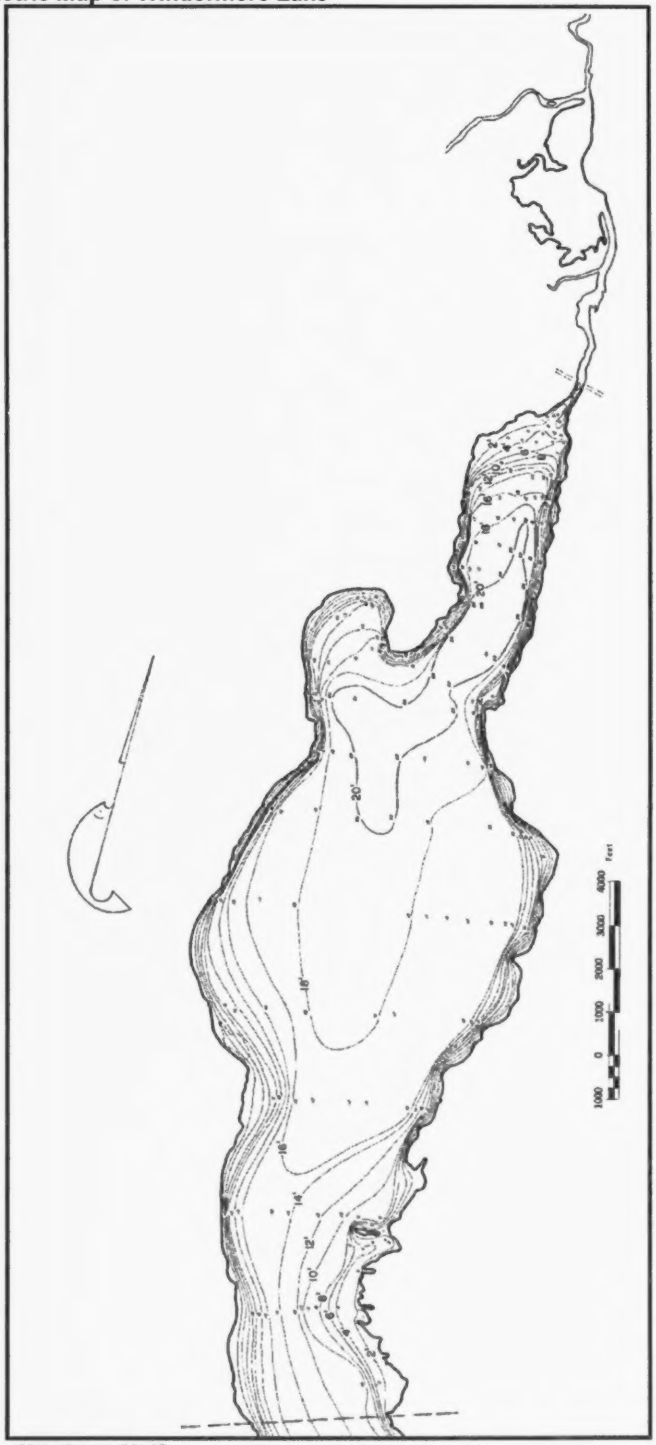
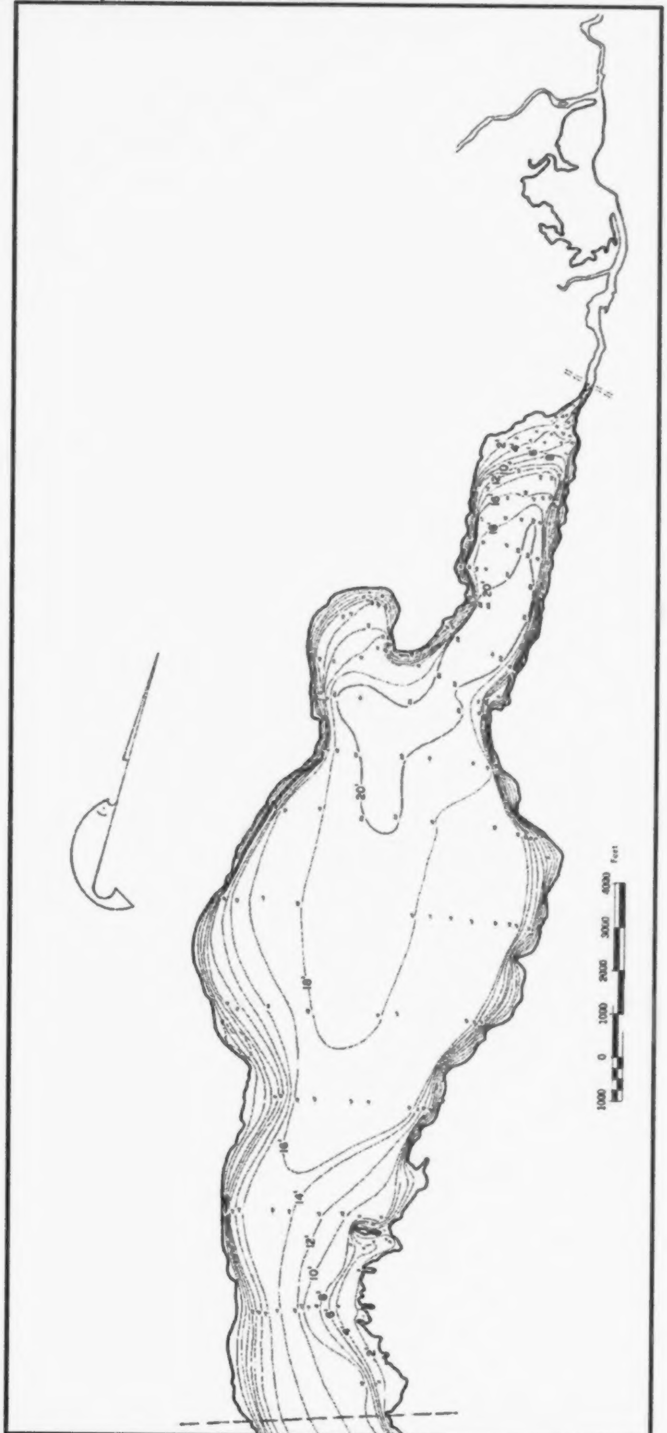
Appendix 1. Bathymetric Map of Windermere Lake

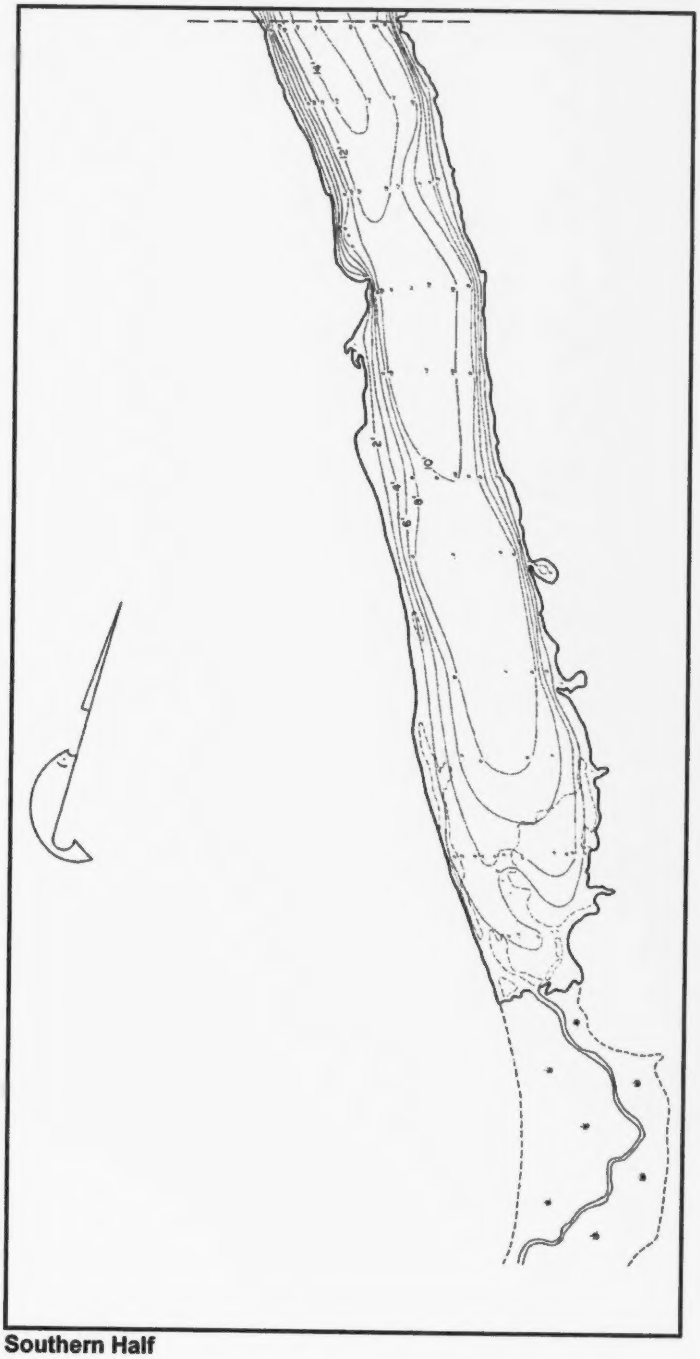


Northern Half

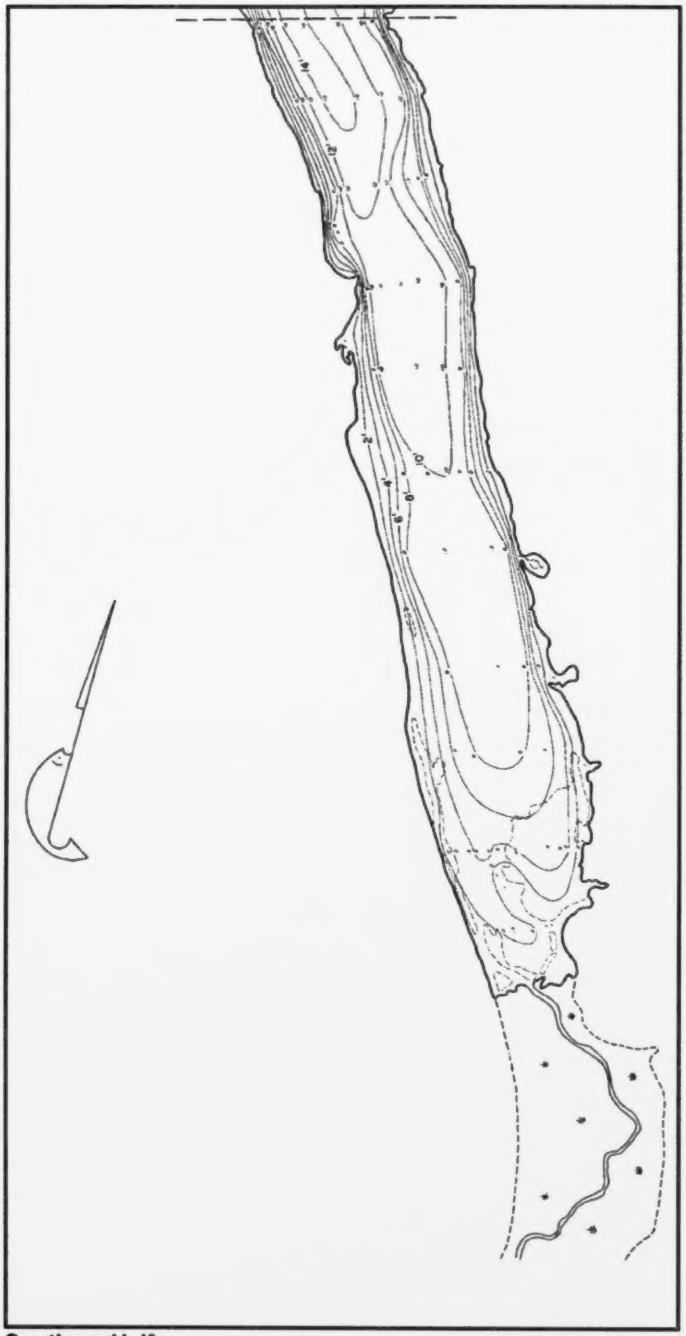
Appendix 1. Bathymetric Map of Windermere Lake



Northern Half



Southern Half



Southern Half

Appendix 2. Data Summary for Windermere Lake off Windermere Creek (0200051)
Data range: May 17, 2006 - April 15, 2009

PARAMETER	UNITS	DEPTH	N	MAX	MIN	MEAN	SD
Site Depth	m		34	3.42	0.21	1.03	0.65
Secchi	m		34	2.80	0.21	1.03	0.49
Temperature	°C	Top	34	24.80	2.83	16.36	5.78
		Bottom	8	24.18	14.88	20.48	3.75
DO	mg/L	Top	25	15.46	7.35	10.62	2.21
		Bottom	5	9.59	7.33	7.80	0.80
Ammonia Dissolved	mg/L	Top	27	0.025	<0.005	0.009	0.006
		Bottom	8	0.007	<0.005	0.005	0.001
Calcium Total	mg/L	Top	27	62.3	20.7	34.8	9.7
Chlorophyll *a*		Bottom	11	2.3	<0.0005	0.2100	0.6932
Hardness Total	mg/L	Top	28	327.0	91.2	160.4	50.8
Magnesium Total	mg/L	Top	26	24.3	9.7	15.7	3.7
Total Kjeldahl Nitrogen	mg/L	Top	12	0.28	0.07	0.117	0.0580
		Bottom	2	0.11	0.08	0.10	0.02
Nitrate & Nitrite Dissolved	mg/L	Top	29	0.127	<0.002	0.012	0.024
		Bottom	8	0.039	<0.002	0.007	0.013
Total Kjeldahl Nitrogen Dissolved	mg/L	Top	17	0.20	0.08	0.15	0.04
		Bottom	6	0.14	0.10	0.12	0.02
Total Organic Nitrogen	mg/L	Top	29	0.27	0.07	0.12	0.04
		Bottom	8	0.14	0.01	0.11	0.04
Total Nitrogen	mg/L	Top	30	0.28	0.08	0.15	0.05
		Bottom	8	0.16	0.08	0.12	0.03
Ortho-phosphate Dissolved	mg/L	Top	28	0.005	<0.001	0.002	0.001
		Bottom	8	0.006	0.001	0.002	0.002
Total Phosphorus	mg/L	Top	29	0.036	<0.002	0.007	0.006
		Bottom	8	0.006	<0.002	0.004	0.001
Total Dissolved Phosphorus	mg/L	Top	29	0.023	<0.002	0.006	0.004
		Bottom	8	0.005	<0.002	0.004	0.001
Non Filterable Residue (NFR)	mg/L	Top	25	12	<4	4.4	1.6
Conductivity	mS/cm	Top	33	0.540	0.190	0.300	0.084
		Bottom	8	0.264	0.185	0.223	0.027
Sulfate Dissolved	mg/L	Top	29	120.0	10.9	44.5	26.6
		Bottom	8	33.6	10.2	19.4	8.8
Sulphide Total	mg/L	Top	29	0.012	<0.005	0.007	0.002
		Bottom	8	0.012	<0.005	0.007	0.003
Turbidity	NTU	Top	29	3.50	0.30	0.89	0.65
pH	pH units	Top	33	9.11	7.87	8.67	0.33
		Bottom	8	8.96	7.89	8.74	0.40

Appendix 3. Data Summary for Windermere Lake off Timber Ridge (0200052)
Data range: May 17, 2006 - April 15, 2009

PARAMETER	UNITS	DEPTH	N	MAX	MIN	MEAN	SD
Site Depth	m		32	7.10	5.14	6.07	0.49
Secchi	m		31	6.60	3.00	4.65	0.87
Temperature	°C	Top	32	25.07	2.39	16.51	6.30
		Bottom	32	22.57	2.50	15.95	6.10
DO	mg/L	Top	24	14.74	7.09	10.04	2.12
		Bottom	24	14.64	1.94	9.36	3.01
Ammonia Dissolved	mg/L	Top	26	0.057	<0.005	0.014	0.013
		Bottom	22	0.045	<0.005	0.014	0.013
Calcium Total	mg/L	Top	25	50.1	24.6	32.6	7.2
Chlorophyll *a*		Bottom	11	1.6000	<0.0005	0.1469	0.4819
Hardness Total	mg/L	Top	28	248.0	108.0	151.5	34.5
Magnesium Total	mg/L	Top	25	22.5	11.4	15.6	2.9
Total Kjeldahl Nitrogen	mg/L	Top	14	0.25	0.07	0.12	0.05
		Bottom	9	0.19	0.07	0.11	0.05
Nitrate & Nitrite Dissolved	mg/L	Top	29	0.036	<0.002	0.005	0.007
		Bottom	24	0.033	<0.002	0.005	0.007
Total Kjeldahl Nitrogen Dissolved	mg/L	Top	15	0.290	0.100	0.179	0.050
		Bottom	15	0.260	0.110	0.180	0.052
Total Organic Nitrogen	mg/L	Top	29	0.20	0.05	0.13	0.04
		Bottom	24	0.20	0.07	0.13	0.04
Total Nitrogen	mg/L	Top	31	0.28	0.07	0.15	0.05
		Bottom	25	0.40	0.07	0.17	0.08
Ortho-phosphate Dissolved	mg/L	Top	28	0.006	<0.001	0.003	0.001
		Bottom	22	0.005	0.001	0.003	0.001
Total Phosphorus	mg/L	Top	30	0.013	<0.002	0.005	0.002
		Bottom	24	0.038	<0.002	0.008	0.008
Total Dissolved Phosphorus	mg/L	Top	28	0.014	<0.002	0.005	0.002
		Bottom	24	0.021	<0.002	0.005	0.004
Non Filterable Residue (NFR)	mg/L	Top	25	4	<4	4	0
Conductivity	mS/cm	Top	33	0.463	0.210	0.285	0.064
		Bottom	29	0.467	0.213	0.284	0.060
Sulfate Dissolved	mg/L	Top	29	80.0	20.0	35.9	15.7
		Bottom	24	71.5	21.0	35.3	14.1
Sulphide Total	mg/L	Top	28	0.010	<0.005	0.006	0.002
		Bottom	24	0.009	<0.005	0.006	0.001
Turbidity	NTU	Top	28	5.80	0.05	0.82	1.01
pH	pH units	Top	33	9.20	8.19	8.66	0.34
		Bottom	30	9.25	8.07	8.64	0.40

Appendix 4. Data Summary for Windermere Lake South Station (E262793)
Data range: May 29, 2006 - April 15, 2009

PARAMETER	UNITS	DEPT	N	MAX	MIN	MEAN	SD
Site Depth	m		31	3.40	1.64	2.46	0.44
Secchi	m		30	3.10	1.37	2.27	0.42
Temperature	°C	Top	31	25.10	3.00	16.35	5.46
		Bottom	31	24.70	3.00	15.92	5.37
DO	mg/L	Top	22	13.25	5.77	9.76	1.90
		Bottom	22	13.47	6.40	9.90	1.79
Ammonia Dissolved	mg/L	Top	28	0.038	<0.005	0.009	0.007
		Bottom	26	0.023	<0.005	0.006	0.004
Calcium Total	mg/L	Top	27	38.4	19.0	27.8	5.37
Chlorophyll *a*		Bottom	9	0.0013	<0.0005	0.0007	0.0003
Hardness Total	mg/L	Top	25	190.0	86.2	135	29
Magnesium Total	mg/L	Top	27	19.9	9.4	15.1	3.2
Total Kjeldahl Nitrogen	mg/L	Top	11	0.14	<0.02	0.08	0.03
		Bottom	11	0.15	0.04	0.09	0.03
Nitrate & Nitrite Dissolved	mg/L	Top	28	0.05	<0.002	0.012	0.015
		Bottom	27	0.05	<0.002	0.012	0.016
Total Kjeldahl Nitrogen Dissolved	mg/L	Top	16	0.35	0.07	0.14	0.06
		Bottom	17	0.23	0.07	0.13	0.04
Total Organic Nitrogen	mg/L	Top	28	0.35	<0.02	0.11	0.06
		Bottom	27	0.20	<0.02	0.11	0.04
Total Nitrogen	mg/L	Top	28	0.35	0.04	0.12	0.06
		Bottom	27	0.23	0.05	0.13	0.04
Ortho-phosphate Dissolved	mg/L	Top	28	0.008	<0.001	0.003	0.002
		Bottom	26	0.006	<0.001	0.003	0.001
Total Phosphorus	mg/L	Top	28	0.028	<0.002	0.006	0.005
		Bottom	27	0.021	0.002	0.006	0.004
Total Dissolved Phosphorus	mg/L	Top	28	0.024	<0.002	0.005	0.004
		Bottom	26	0.020	<0.002	0.005	0.003
Non Filterable Residue (NFR)	mg/L	Top	25	<4	<4	<4	0
Conductivity	mS/cm	Top	31	0.367	0.167	0.250	0.048
		Bottom	29	0.367	0.162	0.245	0.045
Sulfate Dissolved	mg/L	Top	28	35.0	8.8	21.0	7.9
		Bottom	27	40.0	8.9	21.6	8.5
Sulphide Total	mg/L	Top	28	0.158	<0.005	0.012	0.029
		Bottom	26	0.008	<0.005	0.006	0.001
Turbidity	NTU	Top	28	3.80	0.50	1.32	0.93
pH	pH units	Top	31	9.07	7.81	8.40	0.33
		Bottom	29	8.95	7.81	8.41	0.30